Acute Effects of Caffeine on Behavioural and ERP Indices of Attention in Healthy, Low Consumers of Caffeine

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The present study was approved by the University of Tasmania

Human Research Ethics Committee

Statement of Sources

I declare that this report is my own original work and that contributions of others have been duly acknowledged.

Signed Date

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Jake Undy

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Abstract

Caffeine is commonly used to enhance attentional processes. However, contention remains regarding the extent to which each attentional mechanism is affected by caffeine, and whether caffeine enhances attention over-and-above improvements in general arousal and sustained attention. Subsequently, the present study examined the acute effects of caffeine on behavioural (reaction time & accuracy) and electrophysiological (N1 ERP amplitude) measures of attention. During two separate sessions (separated by 7-14 days), twenty (14 female & 6 male) healthy, low consumers of caffeine (<150mg/day) completed an Attentional Network Task prior to ingesting either caffeine (200mg) or placebo, and again 30-minutes following ingestion. While a partial effect of caffeine upon the alerting and executive control networks was found, results of the present study suggested improvements in reaction time and accuracy following caffeine predominantly reflected a maintenance of general arousal and tonic alertness. It was concluded that caffeine primarily enhanced attentional processing by preventing fatigue and sustaining attention.

Caffeine has been used as a means of cognitive enhancement for centuries, typically in the form of coffee and tea (Snel & Lorist, 2011). Today, caffeine is the most commonly consumed psychoactive substance, with over 80% of the human population estimated to ingest it daily (Heckman et al., 2010). Given the prevalence of caffeine consumption, obtaining a comprehensive understanding of its effects on the brain and cognition is essential. Caffeine is a naturally occurring alkaloid found in over sixty plant species, including coffee and cocoa beans, kola nuts, and tea leaves (Spiller, 1997). Caffeine has been added to energy drinks, cola-type soft drinks, pre-work out and dietary supplements, as well as prescription and non-prescription medications (Zhang et al., 2012). Caffeine is typically used for its temporary, relatively mild, fast-acting stimulant effects, namely improved sustained attention, reduced fatigue, and elevated mood (McLellen, Caldwell, & Liebermann, 2016; Nehlig, 2010). Attentional processes often precede other psychological and behavioural functions (e.g., memory, mood, motor-output), and are of central importance throughout the present paper (Becker & Leinenger, 2011; Savill, Moree, Dundon, Marcora, & Klein, 2018). Attention operates to efficiently reduce information overload by directing cognitive resources to necessitous cognitive subsystems (Luck et al., 2000). Attentional performance can be measured using behavioural indices such as reaction time (RT) and accuracy (Eriksen & Erikson, 1974; Posner, 1980). That caffeine can have a cognitive enhancing role in improving behavioural indicators of attention appears close to consensus (Einöther & Giesbrecht, 2013; McLellen et al., 2016). However, contention remains regarding the attentional mechanisms responsible for the performance advantages observed following caffeine consumption, and the extent to which these mechanisms are affected (Brunye, Mahoney, Lieberman, & Taylor, 2010a). Electroencephalography (EEG) and Event-Related Potentials (ERP) can assist with generating specificity regarding the effect of

caffeine on attentional performance (Einöther & Giesbrecht, 2013). While many studies examining the effect of caffeine upon attentional processes have used functional Magnetic Resonance Imaging (fMRI), a gap in the psychopharmacology literature persists regarding EEG/ERPs (Koppelstaetter et al., 2010).

Pharmacology, metabolism and mechanisms of action

Caffeine (1,3,7-trimethylxanthine) can be absorbed through mouth, throat and stomach membranes, with caffeine plasma concentrations peaking as quickly as 30 minutes post-ingestion, with a half-life of approximately 4-6 hours in healthy adults (Adan et al., 2008). Absorption rates can be affected by numerous physiological and environmental factors that can result in greater resistance or sensitivity to caffeine (Yang et al., 2010). Contributing factors include biological age and sex, genetic variability, recent and habitual caffeine use, nicotine and THC use, recent food intake and diet, sleep hygiene, pregnancy, sickness and disease (McLellen et al., 2016; Renda et al., 2015). Once absorbed, caffeine is distributed throughout the body via the blood stream, and readily crosses the blood-brain-barrier, before entering extracellular space immediately prior to various neural membrane (Urry & Landolt, 2014). Located in varying concentrations within the neural membrane are adenosine receptors, where the psychostimulant effects of caffeine appear to begin.

Adenosine is a central nervous system (CNS) neuromodulator, attenuating the activity of vigilance-promoting neurons in the brain stem, basal forebrain, and hypothalamus (Urry & Landolt, 2014; Yang et al., 2010). Adenosine-specific receptors (predominantly A1 & A2a receptors) can be found throughout the CNS, predominantly in the brain stem, hippocampus, cerebral cortex, cerebellum, and hypothalamic nuclei. Adenosine is formed within neurons by intrinsic membrane glycoproteins, released into extracellular space following periods of relatively high energy demand, and gradually

accumulates at adenosine receptors throughout the day, before being cleared during sleep (Urry & Landolt, 2014). As an inhibitory neurotransmitter, when adenosine binds to its receptors, neural activity decreases, and fatigue sets in. Caffeine on the other hand, is an adenosine-receptor antagonist, i.e., it mimics adenosine structurally, but not functionally. When caffeine binds to adenosine receptors it blocks the normal neural reductions and fatiguing effects of adenosine, subsequently extending wakefulness. Neurotransmitters essential for arousal, attentiveness, motricity, motivation, and learning, such as norepinephrine, histamine, acetylcholine, dopamine, serotonin, and glutamate, are either directly or indirectly uninhibited when caffeine binds to adenosine receptors (Oken, Salinsky, & Elsas, 2006; Urry & Landolt, 2014; Yang et al., 2010). This process is thought to largely underlie research that has shown improvements in attentional performance following caffeine ingestion (McLellen et al., 2016).

Attention

Attention refers to the capacity of an individual to operationalise, direct and engage concentrated effort onto a stimulus (Carrasco, 2011; Fan et al., 2002; Petersen and Posner, 2012). Attention can be selective, divided, spatial, and sustained, and can be used to recognise and engage stimuli in different modalities (i.e., visual, auditory, tactile). For visual attention, concentrated effort over an object, features, or a spatial configuration facilitates the formation of a high-resolution focal area and low-resolution visual periphery (Carrasco, 2011). Tasks and stimuli can be prioritised when focused upon, enabling information to be processed selectively. A visually selected stimulus or task is afforded a degree of clarity corresponding to a combination of relatively rapid, reflexive bottom-up influences, largely from limbic and sensory modalities, and slower, more deliberate top-down regulation from neocortical sites (Fan et al., 2005; Yanaka, Saito, Uchiyama, & Sadato, 2010). Examples of simple, bottom-up processes include

arousal, sustained attention, response readiness, and orienting. While complex, top-down processes include executive functions such as response inhibition (Petersen & Posner, 2012).

Behavioural Measures of Attention

Tonic alertness. To quantify simple and complex attentional processes reaction time (RT) and accuracy scores have been assessed on a variety of basic psychomotor tasks (Einöther & Giesbrecht, 2013). Simple reaction time (SRT) tasks involve a single stimulus and response; for example, a button push following the presentation of a target on a computer screen (Dreary, Liewald, & Nissan, 2011). The time required to respond to the presentation of the target stimulus is thought to reflect basic sensory input systems (i.e., a stimulus) and output systems (i.e., a response). When performed repeatedly over time, basic SRT tasks can provide a measure of general arousal and tonic alertness, i.e., non-specific activation of the cerebral cortex in relation to sleep-wake cycles, and the ability to maintain concentration for prolonged periods of time, respectively (Oken, et al., 2006; Ratcliff & Van Dongen, 2011). Throughout the present paper tonic alertness has been used synonymously with sustained attention, of which considerable conceptual overlap occurs. Underlying tonic alertness is a midbrain-thalamus-anterior cingulate cortex (ACC) network, extending to bilateral frontal and parietal cortices (Fan et al., 2005; Yanaka et al., 2010). Several neurotransmitter systems modulate thalamic and cortical activity, including the hippocampal-acetylcholine (sustained attention), locus coeruleus-norepinephrine (vigilance), raphe-serotonin (mood), and tuberomammillary-histamine (arousal) systems (Carter et al., 1995; Oken et al., 2006).

Phasic alertness. On a basic SRT task the addition of a centrally located warning cue (e.g., an asterisk) presented immediately prior to target onset reliably improves RT, indicative of enhanced sensory processing (Fan et al., 2002; Yanaka et al., 2010). This 'warning effect' appears to reflect preparatory neural activation of the midbrain-thalamus-ACC network and pre-supplementary motor area (pre-SMA), the same brain regions involved during tests of tonic alertness (Yanaka et al., 2010). This 'neural priming' is typically experienced as an elevated state of anticipation, referred to as phasic alertness (Oken et al., 2006). Phasic alertness is thought to enhance sensory processing by improving signal-to-noise ratios, subsequently reducing the threshold for a response. Tonic and phasic alertness are considered subsystems of an alerting network (Petersen & Posner, 2012).

Orienting. The warning effect becomes more pronounced with the use of spatial cues; warning cues that reliably predict the location of an upcoming target stimulus (Fan et al., 2002). Orienting refers to the ability of an individual to direct their 'spotlight' of attention away from one stimulus and onto another, assisting in the selection of specific information, and ultimately accelerating response times (Posner, 1980). Orienting can occur in a bottom-up, reflexive manner, as when a threatening stimulus comes into view and attention rapidly shifts toward it (Fan et al., 2009). Reflexive orienting appears to be primarily supported by a cholinergic, ventral frontal-parietal system, which includes the temporo-parietal junction and superior colliculus (Petersen & Posner, 2012). Orienting can also proceed in a top-down, voluntary manner, as when a decision to acquire an object prompts a visual search for said object (Fan et al., 2009). Voluntary orienting of attention occurs more slowly, is more vulnerable to inhibition and appears to be underpinned by a predominantly cholinergic, dorsal frontal-parietal system (Petersen & Posner, 2012). Reflexive and voluntary orienting can be overt, whereby the head and/or

eye shifts toward a target stimulus; or covert, in which the attentional processing of a target stimulus is enhanced without body or eye movements (Hunt & Kingstone, 2003; Posner et al., 1984). Overt and covert orienting appear to be independent structures of the inferior and superior parietal lobe, activated according to bottom-up or top-down regulation (Hunt & Kingstone, 2003).

Response inhibition. In a choice reaction time (CRT) task complexity and uncertainty are added with the introduction of multiple stimuli and responses, indexed by slower RTs and reduced accuracy scores compared with SRT tasks (Dreary et al., 2011). Examples of CRT tasks include flanker-type tests, whereby a target is presented on a computer screen surrounded by flanker stimuli that could facilitate or hinder performance (Eriksen & Eriksen, 1974). The target stimulus could vary, along with the type of response required. If the flanker stimuli are similar, or congruent, to the target stimulus then performance is generally facilitated. Whilst performance is typically hindered when flanker stimuli are contradictory, or incongruent, with the target stimulus (Fan et al., 2002; Dreary et al., 2011). Scores on flanker tasks can provide a measure of top-down executive processes, such as response inhibition, the ability to focus upon a target stimulus while blocking distractor stimuli (Petersen & Posner, 2012). Response inhibition appears to be underpinned by densely dopaminergic innervation in ACC and lateral prefrontal cortices (Fan et al., 2005).

Electrophysiological Measures of Attention

Attentional processes can be investigated at a psychophysiological level by combining psychomotor tasks with electroencephalography (EEG) and Event-Related Potentials (ERP; Luck, Woodman, & Vogal, 2000; Neuhaus et al., 2010). Electroencephalography is a recording technique used to monitor patterns of brain

activity at the scalp (Luck et al., 2000). An averaged ERP waveform is generated by dividing the larger EEG recording into trial-specific segments and averaging all segments according to trial type. An ERP contains a series of positive (P) and negative (N) amplitudes (measured in millivolts), each of which peak at varying latencies (milliseconds), with greater amplitudes indicative of increased cortical activity. An ERP component is referred to with a letter, indicating polarity (Positive or Negative), and a number, indicating peak latency (milliseconds). The visual N100, or N1, ERP component has been shown to correlate with sustained attention and orienting (Luck et al., 2000; Vogal & Luck, 2003; Neuhaus et al., 2010).

Vogel and Luck (2003) demonstrated larger posterior N1 amplitudes on various CRT tasks compared to SRT tasks. This suggested increased cortical activation with greater task complexity. However, this study did not utilise central or spatial warning cues. Neuhaus et al. (2010) used an Attentional Network Task (ANT), which combines a cued detection test (Posner, 1990) with the Eriksen flanker paradigm (Eriksen & Eriksen, 1974), to measure tonic alertness (no warning cue), phasic alertness (central warning cue), orienting (spatial warning cue), and response inhibition (flankers). Averaged ERP N1 modulation was explored across 32 electrode channels, and differences between attentional systems were determined using ERP waveform and topographical analysis. Cue effects on the N1 ERP component were clearly evidenced; spatial cues elicited a significantly greater amplitude than central cues, which elicited a significantly greater amplitude than no cue trials. This was particularly evident at posterior-parietal channels for alerting cues, and posterior-occipital channels for orienting. These findings align with conceptions of attention-related N1 being generated at the extrastriate cortex (Fu, Greenwood, & Parasuraman, 2005; Padilla et al., 2006).

Caffeine on Attention

Alerting. Performance improvements have been consistently demonstrated across various basic psychomotor tasks with a broad range of caffeine doses (37-600mg), strongly suggesting an effect of caffeine on arousal and tonic alertness (Christopher et al., 2005; Einöther & Giesbrecht, 2013; Haskell, Kennedy, Milne, Wesnes, & Scholey, 2008). While RTs showed significant improvement on SRT tasks across several studies, scores were rarely assessed in terms of accuracy (Childs & de Witt, 2006; Fine et al., 1994; Martin & Garfield, 2006). Using a SRT task to assess tonic alertness, Kelemen and Creeley (2001) found caffeine reliably improved both RT and accuracy. On tasks that included warning cue trials, caffeine has been shown to significantly reduce RT, suggesting an enhancement in phasic alertness (Brunye et al., 2010a, 2010b), but not always (Giles et al., 2012; Giles et al., 2016).

Foxe et al. (2012) combined a SRT task with EEG to monitor the effect of caffeine on EEG waveforms. Alpha-band oscillatory activity was significantly reduced following a caffeine dose as low as 50mg (for caffeine content of commonly used products see Table 1). Alpha-band oscillations generally index fatigue and reduced cortical activity (Pfurtscheller, 1992). Subsequently, caffeine seemingly reduced the decline in cortical activity in fatigue-inducing tasks. This parallels with conceptions of caffeine as an adenosine modulator within the CNS, blocking adenosine, and sustaining neural activity (Urry & Landolt, 2014).

Orienting. Smith, Brockman, Flynn, Maben, & Thomas (1993) found early evidence for an improvement in orienting following caffeine. Smith et al. compared twenty-four habitual, moderate (~240mg/day) caffeine consumers on a variety of basic SRT and CRT tasks following either caffeine (1.5 or 3mg/kg dose) or placebo. RTs

improved with caffeine on tasks relevant to orienting. However, the tasks predominantly measured alerting, and large variability in caffeine consumption without a pre-test abstinence period made any caffeine-related conclusions problematic. More recently, caffeine has not been shown to generate orienting effects (Brunye et al., 2010a; Brunye et al., 2010b; Giles et al., 2012; Giles et al., 2016). Brunye et al. (2010a, 2010b) included a 12-hour abstinence period and used an ANT to compare the effect of several caffeine doses (0mg, 100mg, 200mg, 400mg) on alerting, orienting and response inhibition for habitual, low consumers of caffeine (*M*=42.5mg/day) and habitual, high consumers (*M*=592.3mg/day). Although, caffeine did not enhance orienting performance across either study, and a decrement in orienting performance was seen for low caffeine consumers at 400mg. The finding of no differential effect of caffeine upon the orienting network was thought to reflect work that suggests caffeine acts primarily, directly or indirectly, upon densely dopaminergic and norepinergic regions of the striatum, ACC, and frontal cortices, not involved in orienting (Brunye et al., 2010a; Ko et al., 2009; Volkow et al., 2015).

With regards to electrophysiological research, Ruijter, Lorist, Snel and De Ruiter (2000) assessed twelve participants on a ten-minute complex sustained attention task following both caffeine and placebo. A combination of ERP and behavioural indices did not reveal any effect of caffeine on orienting. However, it was suggested the task was probably too demanding to find an effect. The researchers also focused on positively evoked potentials, such as P2 and P3 components. However, studies that have investigated the effect of caffeine on orienting are sparse and limited, particularly those utilising ERP indices, preventing any firm conclusions to be drawn for the effect of caffeine on orienting.

Table 1

Caffeine Content of Commonly Used Products

		Caffeine (mg)
Per 125ml cup		
	Filtered, percolated coffee	60-100
	Instant coffee	35-50
	Cappuccino	60
	Decaf	2-4
	Espresso (per 50ml)	50-60
	Tea	20-45
Per 100ml		
	Iced tea	3-12
	Cola soft drink	3-11
	Energy drinks	30
	Chocolate drinks	2-4
Per 50g		
	Milk Chocolate	2-25
	Dark Chocolate	8-60
	Chocolate ice cream	2-10
	Prescription and non-prescription medication	25-100

Source: Snel and Lorist (2003).

Executive control. Most studies investigating the effect of caffeine on response inhibition have found significant effects of caffeine on performance (Einöther & Giesbrecht, 2013; McLellen et al., 2016). On a CRT task requiring participants to select a central target letter flanked by peripheral distractors, caffeine consistently decreased response times (Christopher et al., 2005; Hewlett & Smith, 2006; Smith et al., 2003) and occasionally improved accuracy (Smith et al., 2005). Utilising Eriksen flanker and Eriksen-adapted flanker tasks, RTs have been shown to improve following caffeine (150-250mg) compared with placebo (Addicott & Laurienti, 2009; Eriksen & Eriksen, 1974; Kenemans, Wieleman, Zeegers, & Verbaten, 1999; Tieges, et al., 2009). More recent research using ANTs showed response inhibition was enhanced by caffeine for low (Brunye et al., 2010a) and moderate-high caffeine consumers (Brunye et al., 2010b; Giles et al., 2012; Giles et al., 2016). These effects were thought to reflect caffeine-induced innervation of densely dopaminergic regions of the ACC and prefrontal cortex (Brunye et al., 2010a; Volkow et al., 2015).

Other studies have failed to show sensitivity of response inhibition to caffeine (Rujiter et al., 2000; Tieges, Snel, Kok, & Ridderinkhof, 2009). Tieges et al. (2009) assessed the effect of a 3mg/kg body weight dose of caffeine on response inhibition. A flanker task was administered to healthy participants in a double-blind, placebo-controlled, within-subjects experiment, and differences in overall performance on the flanker task between caffeine and placebo conditions were negligible. These results were thought to reflect either too small a dose and/or insufficient reversal of adverse withdrawal symptoms (James, 2014). However, this cannot be determined because no baseline data was acquired (Tieges et al., 2009).

Methodological Limitations

Previous studies that measured the behavioural effects of caffeine according to dose have found speed-accuracy advantages as low as 50mg on tests of alertness (Foxe et al., 2012; Wilhelmus et al., 2017). For low caffeine consumers (<150mg/day), alerting and executive control effects tended to reach optimal performance at a moderate dose (~200mg), before asymptoting at higher doses (Brunye et al., 2010a). For habitual, moderate-high consumers (>150mg/day), alerting and executive control effects optimised with a high dose (~350-450mg), and became asymptotic thereafter (Brunye et al., 2010a; Brunye et al., 2010b; Tieges et al., 2004). Recent studies have shown that following longer periods of abstinence, habitual consumers required less caffeine to elicit an effect on performance (Giles et al., 2012). This 'rise and tapering-off' in performance has been interpreted in terms of the classic inverted U-curve of arousal/performance, whereby increasing arousal facilitates improvements in performance, before plateauing and eventually hindering performance (Nehlig, 2010). While confounds such as task difficulty, caffeine sensitivity, body-weight, and personality make the inverted U-curve a somewhat simplistic explanation, the dose-related effect of caffeine appears similarly curvilinear, with an optimal dosage central to the arousal/performance curve (Anderson, 1994; Diamond, 2005; Renda et al., 2015).

The Present Paper

The aim of the present study was to further investigate the effects of caffeine (200mg) on behavioural measures (RT & accuracy) of alerting, orienting and executive control, and electrophysiological measures (N1 ERP component) of alerting and orienting with healthy, low caffeine consumers. An Attentional Network Task (ANT) was used to differentiate between three attentional networks as described by the

Attention Network Theory (Fan et al., 2002; Petersen & Posner, 2012). The ANT is a computer-based activity which combines a cued detection paradigm (Posner, 1980) with a flanker task (Eriksen & Eriksen, 1974). Behavioural measures (RT & accuracy) are used to index performance on the ANT. Evidence from behavioural and neural research provide support for the efficacy of the attentional network theory and ANT for differentiating attentional mechanisms (Fan et al., 2002; Neuhaus et al., 2010; Petersen & Posner, 2012). The present study also indexed neural correlates of attention (tonic, phasic, & orienting) via an occipital N1 ERP component.

The attentional network theory posits that underlying attention are three functionally and anatomically distinct networks; the alerting, orienting and executive control networks (Peterson & Posner, 2012). The alerting network can be discussed in terms of tonic and phasic alertness; where tonic alertness refers to the intrinsic state of arousal or wakefulness of an individual, and phasic alertness refers to the ability of an individual to manipulate the level of response readiness to a stimulus or task. The ANT assesses tonic and phasic alerting with a two-CRT task containing trials with either no warning cue (tonic) or a location-naïve warning cue (phasic). The difference between no cue and central cue conditions reflects an overall score for the alerting network (Fan et al., 2002). Orienting refers to the ability to redirect the 'spotlight of attention' from one stimulus onto another. Orienting is measured by the ANT using a two-CRT task with a spatial warning cue that validly predicts the location of an upcoming target stimulus. The difference between central cue and spatial cue conditions reflects the orienting network. In the context of the ANT the executive control network refers to response inhibition, the ability to block out distracting stimuli to prioritise a target stimulus. Executive control is measured by comparing trials containing congruent flankers with trials containing incongruent flankers. Differentiating between attentional networks

affords the capacity to discern whether caffeine influences specific attentional mechanisms over-and-above general arousal and tonic alertness.

A double-blind, within-subjects design, with two levels of a caffeine condition (0mg, 200mg) was conducted. The influence of caffeine on the attentional networks (alerting, orienting, & executive control) was assessed by combining the ANT with EEG, specifically measuring RT (ms), accuracy (% correct responses), and the N1 ERP waveform at the midline occipital electrode site (Oz). It was expected that on the ANT, participants would exhibit significantly reduced overall RTs following caffeine compared with placebo. More specifically, it was predicted that RTs would be slowest for no cue, significantly faster for central cues (alerting), and fastest for spatial cues (orienting); and that with caffeine RTs would be significantly faster for all cues in comparison to placebo equivalents. Congruent trials were expected to produce significantly faster RTs than incongruent trials, and caffeine was expected to produce significantly faster RTs at congruent and incongruent trials. Greater attentional network effects were expected for alerting and executive control following caffeine, but not orienting. Accuracy scores following caffeine were expected to be significantly higher than placebo. It was predicted that the N1 amplitude would be smallest for no cue, greater for central cue (alerting), and greatest for spatial cue (orienting); and with caffeine, N1 amplitude would be greater for all cues relative to placebo equivalents.

Method

Participants

Twenty-three healthy, low caffeine consuming (M= 45.69mg/day, SD=38.47) participants (6 male, 14 female), aged 19-29 (M=22.10, SD=2.99) were recruited for the present study. An *a priori* G*Power estimate indicated a sample of 24 participants was sufficient to detect moderate sized effects (f=.25, α=.05, power=.90). Three participants

were excluded due to low accuracy (<75%; *n*=2) and withdrawn consent (*n*=1) for a total of 20 participants. While 127 participants completed the screening questionnaire, the aim was to reduce the potential impact of withdrawal and tolerance effects, so only those with no-to-low caffeine consumption (0-150mg/day) were recruited (*M*=45.69, *SD*=38.47). Participants were either psychology undergraduates at the University of Tasmania (UTAS), and received course credit, or paid volunteers recruited via advertisements throughout the UTAS campus, social media, or peer referral, and received a $40 gift voucher for their time and expenses.

The screening questionnaire contained the following exclusion criteria: habitual tobacco use; a history of illicit drug use (any consumption in past month or ≥8 lifetime uses); prescribed medication use; alcohol dependence or abuse as indicated by scores on the Alcohol Use and Disorders Identification Test (AUDIT; Saunders, Aasland, Babor, De la Fuente, & Grant, 1993; exclusion with scores ≥16); high levels of psychological distress as indicated by scores on the Kessler Psychological Scale (K10; Kessler et al, 2002; exclusion with scores ≥30), current or notable history of mental health conditions, contraindications to caffeine such as hypertension or anxiety, and pregnancy. English as first language, normal-corrected vision and hearing, and a body mass index (BMI) higher than 18.5 (not underweight) was also required to participate.

If eligible beyond the screening process, two experimental sessions (approximately 2.5 hours each, 7-14 days apart) at the UTAS Cognitive Neuroscience Laboratory were organized via an anonymous phone call and email correspondence. Participants were asked to refrain from using illicit drugs prior to and during testing, and to abstain from any alcohol use 24 hours prior to testing. To ensure consistency in caffeine consumption, participants were asked to abstain from caffeine at least four hours before arrival. Participants were also asked to limit food intake to a light meal on

the day of testing. Each experimental session began at approximately 1pm to control for potential time-of-day effects (Revelle, Humphreys, Simon, & Gilliland, 1980). The present study was approved by the University of Tasmania Human Ethics Committee (see Appendix A).

Materials and Apparatus

An online screening questionnaire was comprised of items relating to: demographic information; handedness; caffeine intake (type, frequency & quantity); tobacco and nicotine use; alcohol habits; past and present physical, neurological and psychological conditions (e.g., skin sensitivity, epilepsy, anxiety & depressive disorders); medication; BMI; language.

The Alcohol Use and Disorders Identification Test (AUDIT; Saunders et al., 1993) was used as part of the screening questionnaire to assess hazardous alcohol use, alcohol dependence, and problematic patterns of alcohol-related behaviour (Bohn, Babor, & Kranzler, 1995). The AUDIT contains ten questionnaire items, with seven items relating to frequency rated on a 5-point scale (e.g., 'never' to 'daily or almost daily'), two items relating to harmful use rated on a 3-point scale (e.g., 'no' to 'yes, during the last year'), and one item relating to quantity rated on a 5-point scale (e.g., '1 or 2' to '10 or more'). An overall score ≥16 is indicative of problematic use (Saunders et al., 1993). Psychometric properties of the AUDIT, including test-retest reliability and internal consistency, are robust (Bohn et al., 1995; Reinert & Allen, 2007).

The Kessler Psychological Distress Scale (K10; Kessler et al., 2002) was used as part of the screening questionnaire to assess recent psychological wellbeing. The K10 contains ten questionnaire items relating to psychological distress (e.g., 'about how often did you feel depressed?'), rated on a 5-point Likert scale (e.g., from '1= all of the time' to '5= none of the time'). Scores ≥30 indicate a very high level of psychological

distress (Myer, Stein, Grimsrud, Seedat, & Williams, 2007). The K10 is increasingly utilised in neuropsychological research, evidenced to have high internal consistency (Cronbach's α=.93), and been validated across various settings (Andrews & Slade, 2001; Kessler et al., 2002; Myer et al., 2007).

An experimental session questionnaire (See Appendix B) was used during each session to record and control for potentially confounding variables. The checklist contained questions relating to: alcohol and illicit drug use; prescribed and non-prescribed medications; caffeine intake (quantity and recency of use); tobacco and nicotine use; food consumption (types and recency of use); height and weight (BMI); and sleep (quantity).

The Wechsler Test of Adult Reading (WTAR; Wechsler, 2001) assessed verbal intelligence by asking participants to read aloud a list of 50 irregularly spelled words (e.g., 'lugubrious'). A standardised score can be generated by combining the raw score (number of correct responses) with the participants age. Standardised scores on the WTAR have been shown to correlate strongly with overall verbal IQ (r=.75) and full-scale IQ (r=.73; Wechsler, 2001). The WTAR was developed in relation to the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III; Wechsler, 1997), and high internal consistency (Cronbach's α =0.87-0.97) and test-retest reliability (r=.90-.94) have been demonstrated (Wechsler, 2001).

A Profile of Mood States-Short Form (POMS-SF; Shacham, 1983) provided a subjective account of mood at pre- and post-ingestion. The POMS-SF consisted of 37 survey items (e.g., 'energetic') that participants rated on a 5-point scale (e.g., from 0= not at all', to '4= extremely'). The POMS-SF is comprised of nine subscales, including: Tension-Anxiety; Depression-Dejection; Anger-Hostility; Vigour-Activity; Fatigue-Inertia, and; Confusion-Bewilderment. Internal consistency estimates for the POMS-SF

scales appear equivalent and superior to those of the original POMS (Curran et al., 1995; Shacham, 1983).

The Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990) assessed subjective levels of wakefulness at pre- and post-ingestion. The KSS asks participants to circle one of the nine statements that most accurately reflected how they felt, from 1 ('extremely alert') through 5 ('neither alert nor sleepy') to 9 ('very sleepy, great effort to keep awake, fighting sleep'), with lower scores indicating a greater level of wakefulness.

Visual-Analogue Scales (VAS) provided a measure of subjective performance and drug effects (See Appendix C). The VAS of Subjective Performance consisted of four statements regarding alertness (e.g., 'I feel alert'), and were used at pre- and post-ingestion. While the VAS of Subjective Drug Effects consisted of four concentration- and drug-related items (e.g., 'Liking of drug effect'), and were used at post-ingestion. Participants rated themselves for each item by marking along a 10cm black line (e.g., from 'strongly agree' to 'strongly disagree'), thereby scoring between zero and ten, with lower scores indicating greater agreement for VAS-performance items and less effect regarding VAS-drug items. A manipulation check was included in the VAS of Drug Effects questionnaire form, asking participants to indicate their level of confidence in having ingested caffeine (0-100%).

Attentional Network Task

Adapted from Neuhaus et al. (2010), an Attentional Network Task (ANT) was utilised (see Figure 1). The ANT was performed on a computer with NeuroSCAN Stim2 software. For each trial, a white fixation cross (0.2cm) on a black computer screen was presented for 400 milliseconds (ms), followed by a 100ms pseudo-randomised generation of one of three cue stimuli: central cue, spatial cue, or no cue. The central

cue involved the presentation of a white asterisk (0.4cm) overlaying the central fixation cross. The spatial cue also involved the appearance of an asterisk (0.4cm), but 1.01 degrees above or below the central fixation point, always validly predicting the location of an upcoming target stimulus.

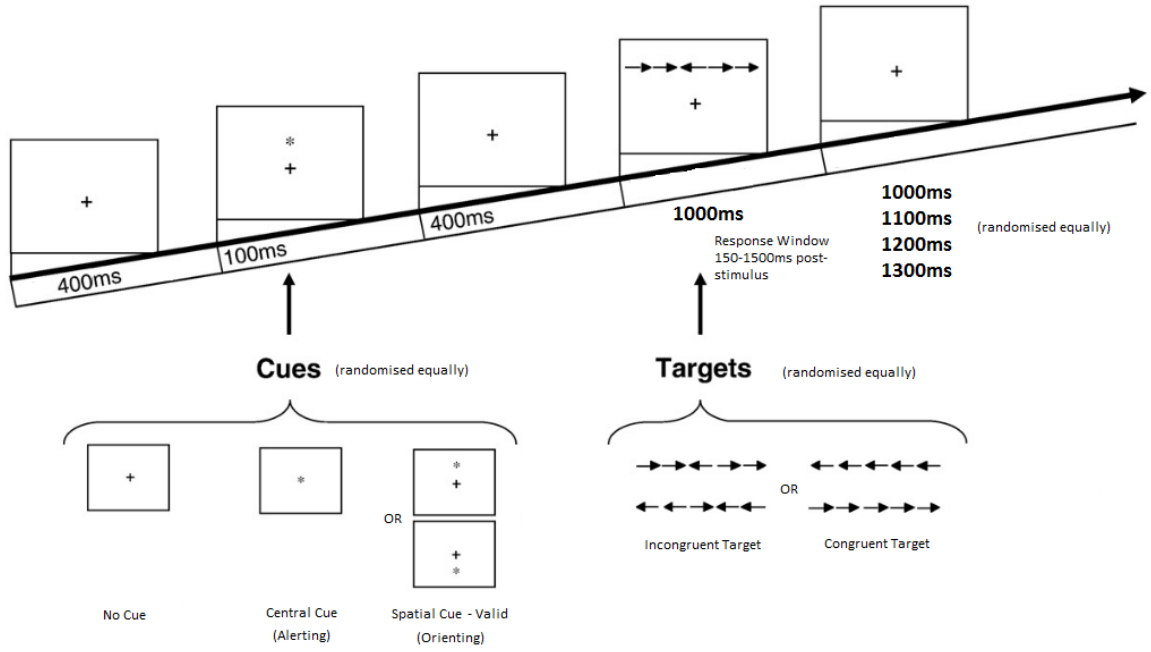

Figure 1. The Attentional Network Task (adapted from Neuhaus et al., 2010).

A 400ms inter-stimulus interval (ISI) separated the cessation of the central and spatial cues and the presentation of the target stimulus. For no cue trials an asterisk did not appear on screen, and instead the central fixation cross remained on screen until the presentation of a target stimulus. The target stimulus was the central arrow within a 3.4cm row of five horizontally-directed arrows (pointed either left or right). The row of arrows remained on screen for 1000ms or until a left-or-right response was selected. Responses were made via a left-or-right button push on a Cedrus Response Pad (Model RB-740). A left-pointed target arrow indicated a left button push using a left-hand index

finger, and vice-versa for a right-pointed target arrow. The two arrows on each side of the target arrow (flankers) were either congruent (pointed in the same direction as the central arrow) or incongruent (pointed in opposite direction as central arrow). Inter-trial intervals of 1000ms, 1100ms, 1200ms, or 1300ms were randomly allocated to each sequence of trials. The task consisted of 10 practice trials followed by 480 test trials (with an opportunity for a break every 120 trials).

Electrophysiological (EEG) recording

Cortical activity was recorded using a 32-channel Quik-Cap, connected to a computer-based NeuroSCAN system (Scan 4.5 software). Electrode impedance was kept at less than 10kΩ, with electrical activity of the scalp continuously recorded at 1000Hz via 32 electrode sites, in accordance with the international 10-20 electrode placement system (Nuwer et al., 1998). All channels were referenced to an electrode at each mastoid, and horizontal and vertical electro-oculographic activity were recorded from the outer canthi of each eye and above and below the left eye, respectively.

Continuous EEG and behavioural data were merged and filtered through a Zero-phase-shift low-pass filter (30Hz, 24Db/Oct) during the editing process. Ocular artefact rejection was utilised to reduce potential signal contamination due to eye blinks, eye rotation and head movements. Epochs of 1000ms, beginning 100ms prior to stimulus presentation and finishing 900ms post-stimulus, were extracted from the dataset. Baseline correction and artefact rejection were performed on each epoch, with artefacts excluded above 70µV or below -70µV. The N1 amplitude at the midline electrode (Oz) was then determined via a grand averaging of EEG waveforms across all participants for each condition. An automated peak-selection procedure determined the occipital N1, pin-pointing the maximum amplitude from 80-140ms post-stimulus onset, followed by visual inspection and manual correction.

Drug Preparation and Randomisation

Each capsule contained either 100mg of caffeine (No Doz) and gluten-free cornflower filler, or only gluten-free cornflower. All capsules were indistinguishable, equivalent in weight, shape, colour and size, blinding participants and experimenters to the drug condition. The caffeine drug condition included two capsules for a total of 200mg caffeine, an optimal dose for low caffeine consumers (Brunye et al., 2010a). While the placebo condition included two capsules of gluten-free cornflower. Randomisation and counterbalancing of drug condition were conducted independently of experimental researchers. Prior to participant recruitment, capsules were packaged in identical envelopes by a chief researcher according to a counterbalanced drug presentation sequence. To complete the double-blind, the chief researcher in question remained absent during experimental sessions.

Procedure

Eligible participants were invited to the UTAS Cognitive Neuroscience Lab for two experimental sessions of approximately two-and-a-half hours. All sessions began at approximately 1pm and were separated by at least one week. On arriving for the first session, each participant was given an information sheet and consent form (see Appendix D). Participants were then setup with EEG recording equipment and relocated to an adjacent room and seated at eye line with the centre point of a computer screen. Participants were briefed on the upcoming computer task, either the ANT or Flanker Task (not discussed in the present study). Participants were asked to respond to each trial as quickly and accurately as possible while limiting eye and body movements. Computer tasks were presented in counterbalanced order across participants and took approximately forty-five minutes to complete. Immediately after the computer tasks,

pre-ingestion measures (POMS, KSS, VAS-performance) were completed, and the EEG Quik-Cap was temporarily disconnected. Each participant was provided with a glass of water (250mL) and an envelope containing two of either caffeine (200mg) or placebo capsules. A thirty-minute break began once the capsules had been ingested, enough time for plasma caffeine concentration to peak (Adan et al., 2008). During the break participants completed the WTAR and experimental questionnaire, followed by a relaxation period. The computer tasks were completed for a second time (same order), followed by post-ingestion measures (POMS, KSS, VAS-performance, VAS-drug effects, blinding check), and a disassembling of the EEG Quik-Cap. Upon completion of the second session (1st session repeated, but with alternate drug condition) participants were debriefed, and compensated for out-of-pocket expenses (gift voucher and/or course credit).

Design and Data Analysis

Behavioural measures included RT (ms) and accuracy (% correct responses) scores from the ANT. False starts (i.e., RTs <150ms) and extraordinarily slow responses (>3 SDs) were removed from the dataset. Accuracy data was only reported for main effects and interactions with statistical significance (p<.05) and theoretical relevance (e.g., speed-accuracy trade-off). Planned pairwise comparisons were conducted for RT and accuracy to measure the effect of Drug across Cue, Flanker and Time.

To investigate the effect of caffeine on behavioural measures of alerting, orienting and executive control networks, a 3 (Cue: No Cue, Central Cue Spatial Cue) x 2 (Flanker: Congruent, Incongruent) x 2 (Drug: Placebo, Caffeine) x 2 (Time: Pre-ingestion, Post-ingestion) repeated measures ANOVA was initially conducted for RT and accuracy. Attentional networks were then calculated for RT by generating an

averaged difference between No Cue and Central Cue (Alerting), Central Cue and Spatial Cue (Orienting), and Congruent and Incongruent Flankers (Executive Control) for placebo and caffeine scores at post-ingestion. A 2 (Drug; Placebo, Caffeine) x 3 (Network; Alerting, Orienting, Executive Control) repeated measures ANOVA was conducted, and planned pairwise comparisons subsequently performed.

To investigate the effect of caffeine on electrophysiological measures of alerting and orienting, a 3 (Cue: No Cue, Central Cue Spatial Cue) x 2 (Flanker: Congruent, Incongruent) x 2 (Drug: Placebo, Caffeine) x 2 (Time: Pre-ingestion, Post-ingestion) repeated measures ANOVA was conducted for the peak amplitude (μV) of the N1 ERP component and pairwise comparisons performed. The N1 amplitude was analysed at the occipital midline (Oz) electrode site. Electrophysiological (EEG) analysis excluded three datasets due to EEG malfunction. To account for the missing ERP data, a mixed-models ANOVA was performed, revealing no deviation from the initial ANOVA. With respect to the principle of parsimony (Epstein, 1984), results reported in the present study were generated from the repeated-measures ANOVA output.

To investigate the effect of caffeine on subjective reports of mood and sleepiness, 2 (Drug: Placebo, Caffeine) x 2 (Time: Pre-ingestion, Post-ingestion) repeated measures ANOVAs were conducted across the POMS-SF subscales and KSS ratings. Baseline checks for recent caffeine intake, sleep, sleepiness (KSS), subjective performance (VAS), and POMS-SF subscales were assessed between drug conditions via paired-samples t-tests. Post-ingestion manipulation checks, including subjective drug effects (VAS) and caffeine ingestion confidence (0-100%), were assessed with a paired-samples t-test and Related-Samples Wilcoxon signed Rank Test, respectively.

Assumptions of ANOVA were checked to determine the appropriateness of each dataset for further analysis. The assumption of sphericity was likely violated for

interactions and effects involving Cue and Network (3 levels). Greenhouse-Geisser corrected output was subsequently reported for effects involving Cue and Network. Interactions were only reported with statistical significance ($p<.05$) and/or theoretically relevance. Bonferroni corrections were applied to tests of simple main effects. With 20 participants, the present study fell slightly short of initial power estimates (24 participants). Subsequently, the utility of the *p*-value was somewhat diminished (Durlak, 2009). However, effect sizes are not as vulnerable to low statistical power as *p*-values, and subsequently were essential for interpretation of the present findings.

In the current study, partial eta squared (η_p^2), the amount of variance in a dependent variable able to be explained by an independent variable (Cohen, 1973), was used to indicate the effect sizes for omnibus ANOVAs. Effect sizes for η_p^2 were interpreted according to Cohen's (1988) guidelines, with 0.01=small, 0.06=medium, and 0.14=large. Hedge's *g* corrects for bias within small samples (Lakens, 2013), and was therefore applied to tests of simple effects, with effect sizes interpreted as 0.2=small, 0.5=medium, and 0.8=large (Cohen, 1992).

Results

Demographic and Screening Variables

Descriptive statistics for demographics and questionnaire measures can be viewed in Table 2. All participants reported low-to-no caffeine consumption (0-150mg/day), were predominantly university educated, within the normal-superior range of intelligence (WTAR), and not underweight (BMI). Participants were not problematic alcohol consumers (AUDIT), and not highly distressed (K10).

Table 2

Demographic and Screening Variables

Variable	*M (SD)*	*Range*
Age (Years)	22.10 (2.99)	19-29
Education (% completed Grade 12)	95%	11-12
Education (% present/post-university)	75%	NA
Handedness (% right-handed)	95%	NA
Body Mass Index (BMI)	24.4 (3.91)	19-34
Alcohol Use (AUDIT)	4.20 (3.75)	0-15
Psychological Distress (K10)	14.50 (2.61)	10-20
General Intelligence Estimate (WTAR)	112.45 (7.37)	97-124
Caffeine Consumption (mg/day)	45.69 (38.47)	0-144

Note: *M*= Mean, *SD*= Standard Deviation

Baseline Measures and Manipulation Check

A comparison of participants at baseline on potentially confounding variables are presented in Table 3. For placebo and caffeine conditions no significant differences were seen for caffeine intake, sleep, and subjective ratings of sleepiness, alertness. Comparisons made at post-ingestion are therefore likely to reflect drug effects.

Table 3

Comparison of Baseline Variables Between Placebo and Drug Conditions

Baseline Measures	Placebo *M (SD)*	Caffeine *M (SD)*	*t* (1,19)	*p*	*g*
Caffeine Intake (per 100mg)	.11 (.32)	.11 (.32)	NA	NA	NA
Sleep (Hours)	8.04 (1.35)	7.60 (2.1)	1.099	.286	0.24
Sleepiness (KSS)	5.90 (1.37)	5.60 (1.47)	1.031	.316	0.17
Alertness (VAS)	3.24 (1.86)	3.01 (1.80)	.576	.571	0.12

Note: M=Mean, *SD*=Standard Deviation

Participants reported significantly higher confidence (0-100%) in having ingested caffeine when in the active condition (*M*=64.63, *SD*=26.33) than the placebo condition (*M*=29.55, *SD*=31.45), as measured by a Related-Samples Wilcoxon signed Rank Test, *Z*=2.758, *p*=.006. Caffeine confidence scores were highly variable for both the active (range=10-100%) and placebo conditions (range=0-80%). Perceived effects of drug (as measured by the VAS-Drug Effects) were significantly higher following caffeine (*M*=5.12, *SD*=1.62) compared with placebo (*M*=2.87, *SD*=1.88), *t*(18)=3.765, *p*<.001, *g*=1.26.

Mood and Sleepiness

Descriptive statistics for mood (POMS-SF) and sleepiness (KSS) for Drug x Time are displayed in Table 4. A series of 2x2 repeated measures ANOVAs revealed a significant Drug x Time interaction for Confusion-Bewilderment, *F*(1,18)=5.268, *p*=.033, η_p^2=.21. Confusion-Bewilderment decreased significantly from pre-ingestion compared to post-ingestion following caffeine, *p*=.006, *g*=0.75. Following placebo, Confusion-Bewilderment was not significantly different from pre-ingestion to post-

ingestion, p=.881, g=0.03. At pre-ingestion, Confusion-Bewilderment was not significantly different between caffeine and placebo, p=.343, g=0.21. While at post-ingestion, Confusion-Bewilderment was significantly less for caffeine compared with placebo, p<.001, g=0.92.

Table 4

Means (SD) for Mood (POMS-SF) and Sleepiness (KSS) at Pre- and Post-Ingestion

	Placebo		Caffeine	
	Pre	Post	Pre	Post
POMS Subscales				
Depression-Dejection	1.29 (0.53)	0.57 (0.27)	1.24 (0.49)	0.14 (.10)
Tension-Anxiety	2.76 (0.56)	2.14 (0.55)	2.33 (0.59)	2.43 (0.52)
Anger-Hostility	.91 (0.32)	0.52 (0.21)	0.52 (0.26)	0.24 (0.19)
Vigour-Activity	5.47 (0.98)	4.33 (0.82)	4.91 (0.78)	7.29 (1.18)
Fatigue-Inertia	6.05 (0.59)	7.00 (0.86)	5.00 (0.74)	3.86 (0.79)
Confusion-Bewilderment	1.71 (0.28)	1.76 (0.33)	1.52 (0.27)	0.71 (0.30)
Sleepiness (KSS)	5.78 (1.31)	5.84 (1.60)	5.52 (1.46)	4.36 (1.53)

Note: Pre and Post refer to pre-ingestion and post-ingestion. The KSS ranged from 1-9; higher ratings correspond to greater levels sleepiness. Confusion-Bewilderment ranged from 0-20. Fatigue-Inertia from 0-20, Vigour-Activity from 0-24, Anger-Hostility from 0-28, and Depression-Dejection from 0-32; higher ratings correspond to greater levels of indicated mood.

A Drug x Time interaction for Vigour-Activity was also found, $F(1,18)=7.589$, $p=.012$, $\eta_p^2=.275$. Vigour-Activity significantly increased from pre-ingestion to post-ingestion following caffeine, $p=.010$, $g=0.60$. Following placebo, Vigour-Activity was not significantly different from pre-ingestion to post-ingestion, $p=.065$, $g=0.27$. At pre-ingestion, Vigour-Activity was not significantly different between caffeine and placebo, $p=.343$, $g=0.15$. While at post-ingestion, Vigour-Activity was rated as significantly higher following caffeine compared with placebo, $p=.028$, $g=0.73$.

A trending toward significant Drug x Time interaction was found for Fatigue-Inertia, $F(1,18)=3.958$, $p=.060$, $\eta_p^2=.165$. No significant difference in Fatigue-Inertia at pre-ingestion compared to post-ingestion for either caffeine, $p=.168$, $g=0.31$, or placebo, $p=.309$, $g=0.21$. At pre-ingestion, Fatigue-Inertia was not significantly different between caffeine and placebo, $p=.237$, $g=0.39$. While at post-ingestion, Fatigue-Inertia was rated as significantly higher following placebo compared with caffeine, $p=009$, $g=0.81$.

Analysis of sleepiness (KSS) revealed a significant Drug x Time interaction, $F(1,18)=5.267$, $p=.034$, $\eta_p^2=.226$. Following caffeine, ratings of sleepiness significantly reduced from pre-ingestion to post-ingestion, $p=.008$, $g=0.75$. For placebo, sleepiness ratings did not significantly differ from pre-ingestion to post-ingestion, $p=.841$, $g=0.03$. At pre-ingestion, ratings of sleepiness were not significantly different between the caffeine and placebo conditions, $p=.316$, $g=0.26$. At post-ingestion, sleepiness ratings significantly reduced with caffeine compared to placebo, $p=.011$, $g=0.92$.

Reaction Time

Descriptive statistics for RT (milliseconds) across Drug, Cue, Congruency, Drug and Time can be viewed in Table 5. The effect of Cue on RT was statistically

significant and large in magnitude, $F(2,19)=350.634$, $p<.001$, $\eta_p^2=.949$. Pairwise comparisons showed that overall, the spatial cue was significantly faster than the central cue, which was significantly faster than no cue, $p<.001$ for each comparison.

Table 5

Averaged Reaction Times (ms) Across Drug, Flanker, Cue and Time.

			Pre-Ingestion		Post-Ingestion	
Drug	Flanker	Cue	M	SD	M	SD
Placebo	Congruent	No Cue	492.26	38.59	493.57	40.19
		Central	469.11	43.17	462.15	40.55
		Spatial	424.35	39.00	423.28	36.48
	Incongruent	No Cue	563.48	36.34	562.87	42.19
		Central	549.90	46.08	548.18	45.14
		Spatial	489.16	36.51	491.74	37.75
Caffeine	Congruent	No Cue	484.23	36.21	474.77	37.46
		Central	463.71	40.07	446.97	42.39
		Spatial	422.20	36.69	405.43	33.92
	Incongruent	No Cue	558.27	44.43	543.29	44.17
		Central	549.79	50.08	530.94	44.44
		Spatial	486.25	44.15	463.63	41.30

Note: *M*= Mean, *SD*= Standard Deviation

The main effect of Drug was not statistically significant, $F(1,19)=3.735$, $p=.068$, $\eta_p^2=.164$. However, a trend toward statistical significance and a large magnitude of effect was evidenced for the two-way Drug x Time interaction $F(1,19)=3.581$, $p=.074$

η_p^2=.159 (see Figure 2). Pairwise comparisons indicated significantly reduced RTs following caffeine compared to pre-ingestion, *p*=.004, *g*=0.42. While RTs following placebo did not significantly differ from RTs at pre-ingestion, *p*=.866, *g*=0.03. At post-ingestion, RTs were significantly faster following caffeine than placebo, *p*=.001, *g*=0.51. While at pre-ingestion, RTs did not significantly differ between caffeine and placebo conditions, *p*=.676, *g*=0.07.

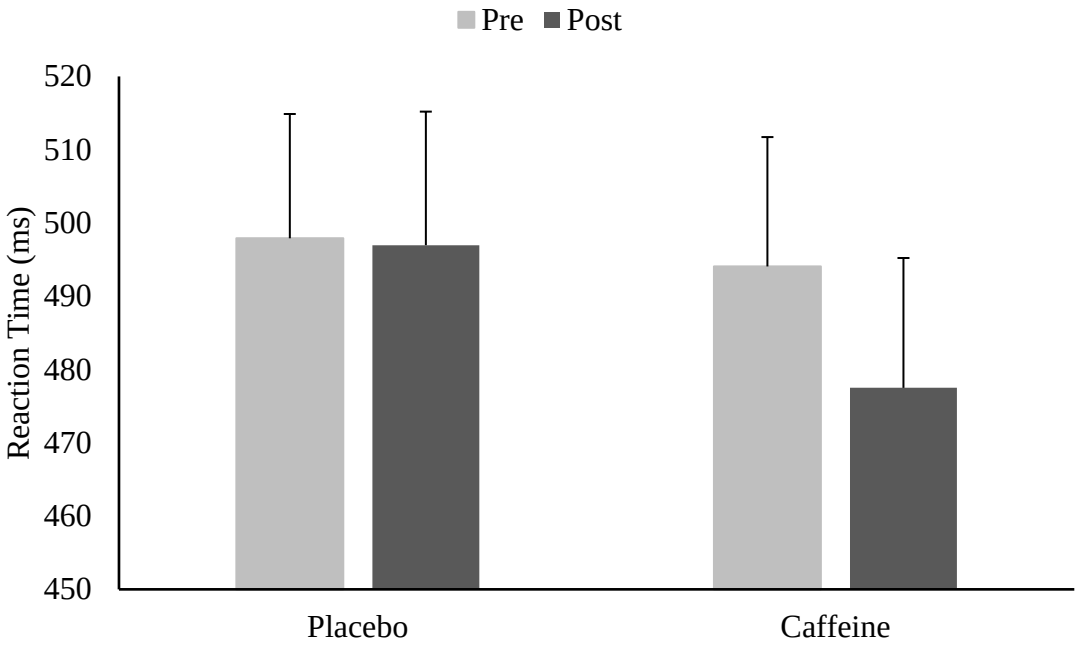

Figure 2. Overall reaction time (ms) at pre- and post-ingestion following caffeine and placebo (error bars represent 95%CIs).

The hypothesised Drug x Time x Cue interaction was not significant, *F*(2,38)=2.091, *p*=.140, η_p^2=.099. However, a trend toward significance and a moderate effect size warranted further analysis (see Figure 3). Across Cues, a significant effect of Drug was found at post-ingestion, *F*(3,17)=7.174, *p*=.003, η_p^2=.56, but not at pre-ingestion, *F*(3,17)=0.593, *p*=.626, η_p^2=.095. Planned pairwise comparisons revealed that

at post-ingestion, No Cue trials were responded to significantly faster (RT) following caffeine than placebo, p=.004, g=0.48. Response times for Central Cue trials were also significantly faster following caffeine than placebo, p=.006, g=0.39. While RTs for Spatial Cue trials were also significantly faster with caffeine compared with placebo, p<.001, g=0.62. At pre-ingestion, there were no significant differences between placebo and caffeine conditions for each of the Cues (p >.05).

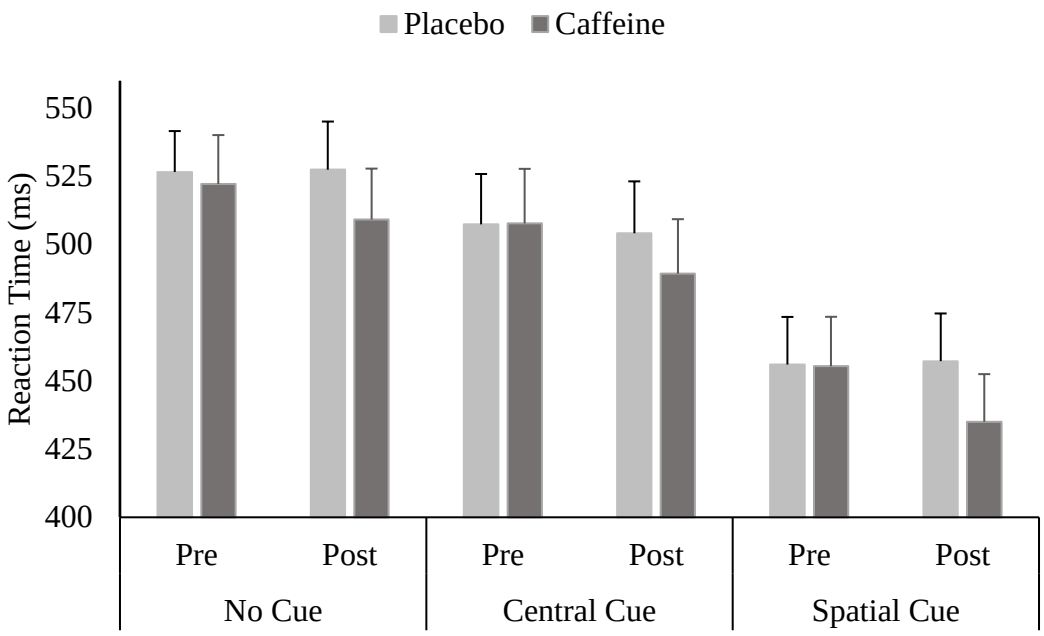

Figure 3. Reaction Time (ms) following each Cue at pre-ingestion and post-ingestion with caffeine and placebo (error bars represent 95%CIs).

Across Cues, a significant effect of Time was also found for caffeine, F(3,17)=6.858, p=.003, η_p^2=.55, but not placebo, F(3,17)=0.623, p=.610, η_p^2=.10. A small effect suggested RTs on No Cue trials in the caffeine condition were faster at post-ingestion than at pre-ingestion, p=.051, g=0.31. For Central Cues, RTs were

significantly faster in the caffeine condition at post- than at pre-ingestion, $p<.001$, $g=0.42$. For Spatial Cues, RTs were significantly faster with caffeine at post- than at pre-ingestion, $p<.001$, $g=0.51$. For each Cue RTs did not significantly differ from pre- to post-ingestion following placebo (all >.05).

A three-way Drug x Time x Flanker interaction was significant, $F(1,19)=6.159$, $p=.023$, $\eta_p^2=.245$ (See Figure 4). For congruent trials, RTs were significantly faster following caffeine than placebo, $p=.002$, $g=0.47$. While at pre-ingestion, RTs for caffeine did not significantly differ from placebo, $p=.544$, $g=0.14$. From pre-ingestion to post-ingestion RTs were significantly faster following caffeine, $p=.010$, $g=0.38$, but not placebo, $p=.726$, $g=0.06$.

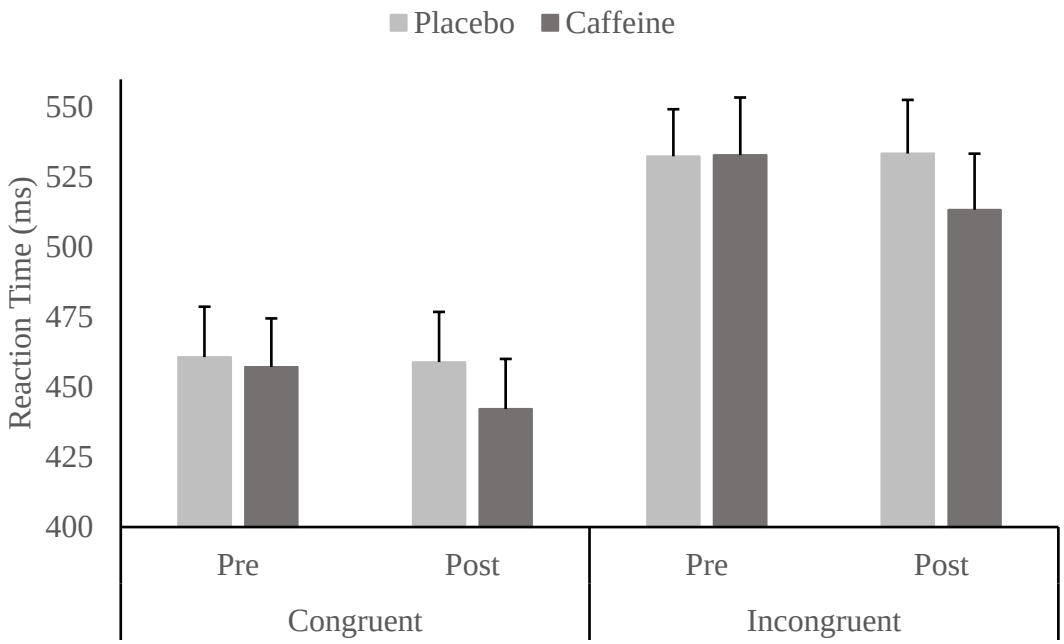

Figure 4. Reaction Time (ms) following each Flanker at pre-ingestion and post-ingestion with caffeine and placebo (error bars represent 95%CIs).

For incongruent trials, RTs were significantly faster following caffeine compared with placebo, p=.002, g=0.53. While at pre-ingestion, RTs for caffeine did not significantly differ from placebo, p=806, g=0.06. From pre-ingestion to post-ingestion RTs were significantly faster following caffeine, p=.002, g=0.42, but not placebo, p=.726, g=0.01.

The hypothesised Drug x Network interaction trended toward significance and was analysed, $F(1.49,28.25)=2.404$, p=.121, η_p^2=.112 (see Figure 5). Pairwise comparisons with Bonferroni correction (α=.017) showed Alerting effects were not significantly different between placebo (M=23.05, SD=11.39) and caffeine (M=20.01, SD=12.43), p=.450, g=0.25.

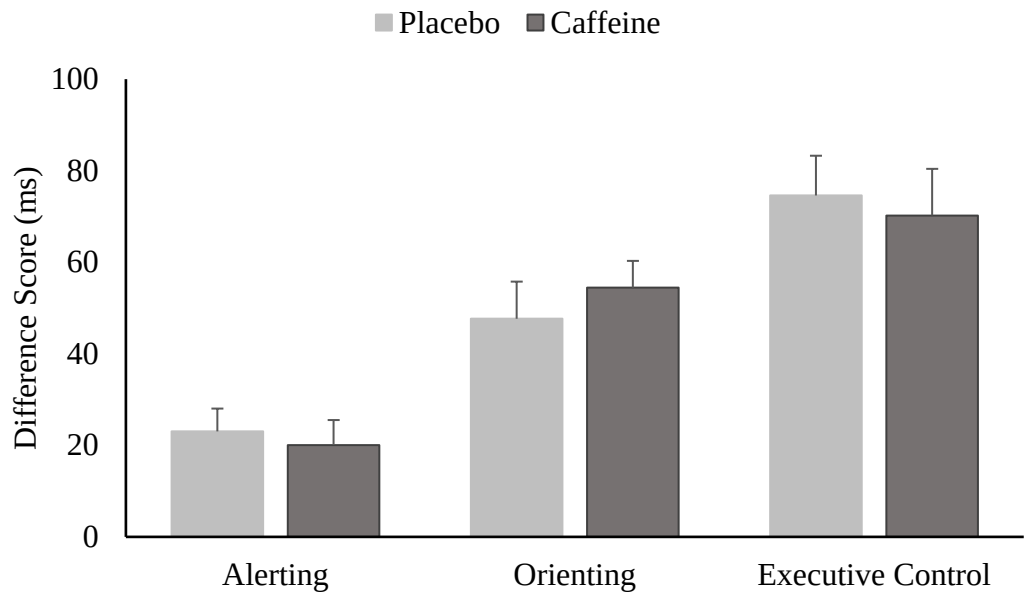

Figure 5. Difference scores (ms) for caffeine and placebo at post-ingestion (error bars represent 95%CIs). Note that higher difference scores for Alerting and Orienting indicate a greater effect, while lower difference scores for Executive Control indicate a greater effect.

Orienting effects were not significantly greater for caffeine (*M*=54.43, *SD*=13.39) than placebo (*M*=47.66, *SD*=18.52), *p*=.023. A small-medium effect size indicated a meaningful difference was found, *g*=0.41. Executive Control effects were not significantly different between placebo (*M*=74.59, *SD*=19.8) and caffeine (*M*=70.23, *SD*=23.24), *p*=.280, *g*=0.19.

Accuracy

The hypothesised Drug x Cue x Time interaction was non-significant, $F(1,18)=.826$, $p=.45$, $\eta_p^2=.04$. However a significant Drug x Time interaction was found, $F(1,19)=4.800$, $p=.041$, $\eta_p^2=.20$ (see Figure 6). At post-ingestion, accuracy was significantly greater following caffeine (*M*=96.95, *SD*=1.44) than placebo (*M*=94.77, *SD*=3.68), *p*=.012, *g*=0.76. While at pre-ingestion accuracy did not differ significantly between caffeine and placebo, *p*=.867, *g*=0.03.

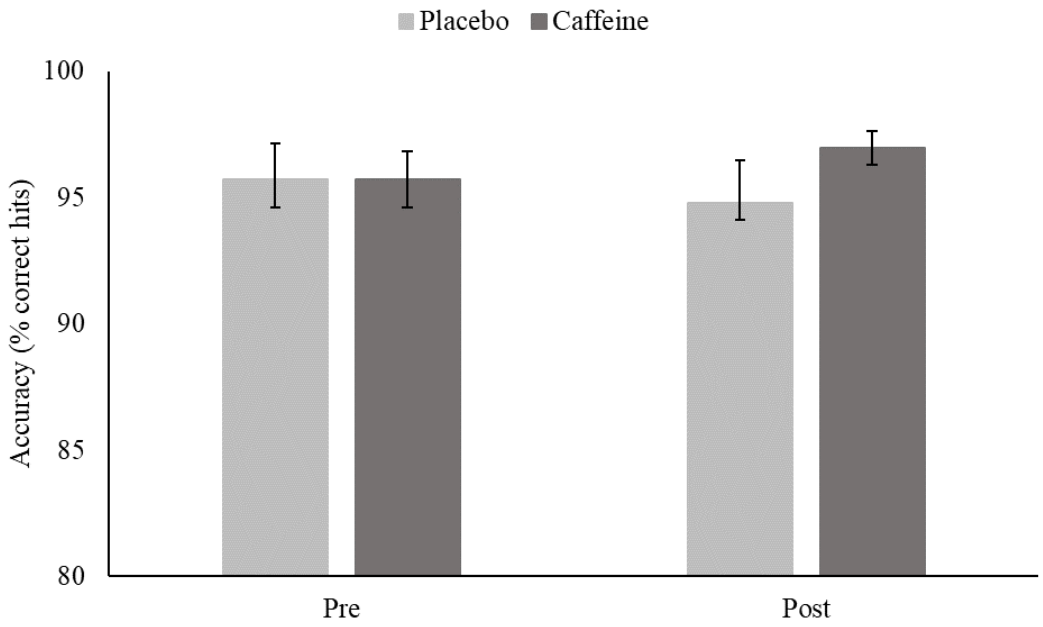

Figure 6. Accuracy (% correct responses) at pre-ingestion and post-ingestion following placebo (left) and caffeine (right; error bars represent 95%CIs).

Pairwise comparisons revealed a significant increase in accuracy for caffeine at post-ingestion (M=96.95, SD=1.44) compared to pre-ingestion (M=95.74, SD=2.38), p=.023, g=0.60, and a non-significant difference from pre-ingestion (M=95.83, SD=2.99) to post-ingestion (M=94.77, SD=3.68) following placebo, p=.145, g=0.31.

N1 Amplitude

Electrophysiological (EEG) analysis excluded three datasets due to EEG malfunction. The grand mean waveforms (μV) generated at the midline occipital (Oz) electrode site can be viewed for caffeine and placebo at Figures 7 and 8, respectively. The averaged grand mean waveform for N1-Oz peaked at approximately 160ms post-stimulus.

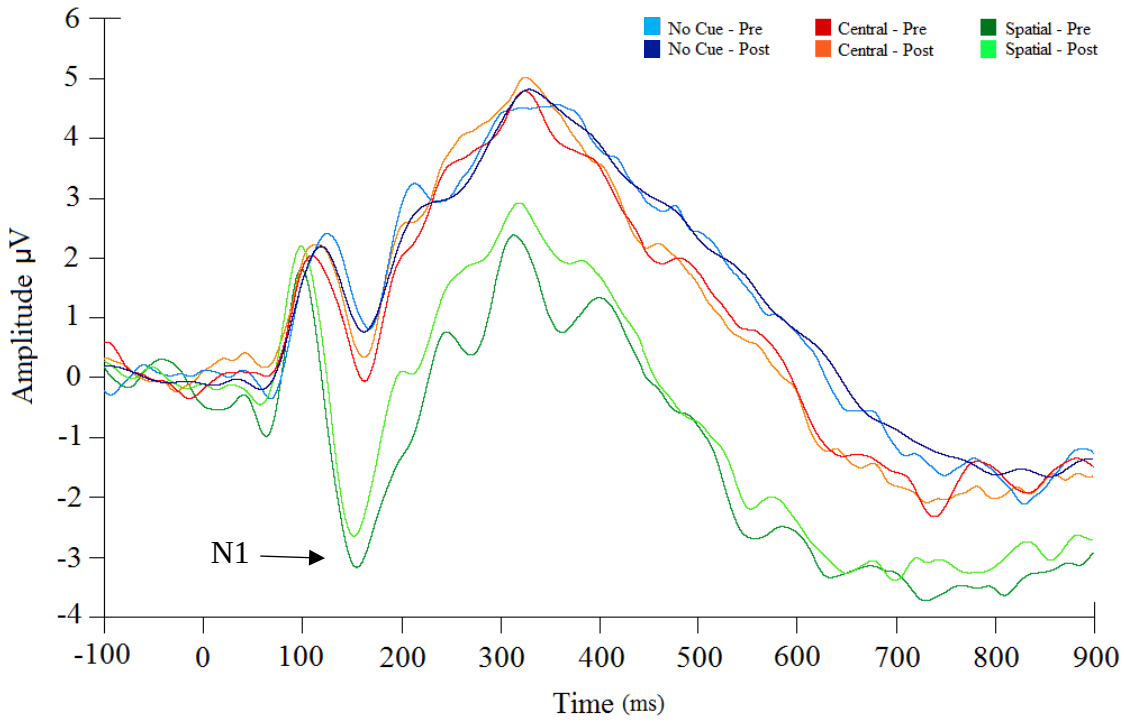

Figure 7. Grand averaged N1 ERP amplitude for Caffeine at midline occipital electrode (Oz) following each Cue at pre- and post-ingestion.

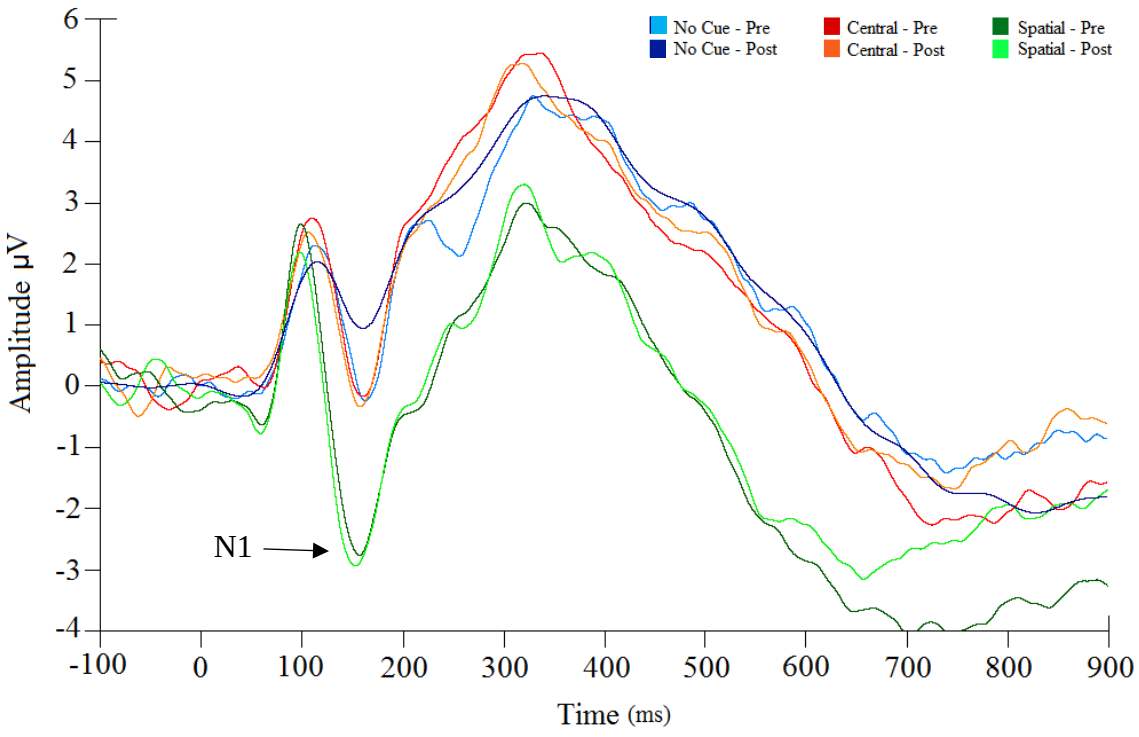

Figure 8. Grand averaged N1 ERP amplitude for Placebo at midline occipital electrode (Oz) following each Cue at pre- and post-ingestion.

The effect of caffeine on the N1 ERP component is visually apparent for No Cue, at which the reduction in amplitude (µV) from pre-ingestion to post-ingestion seen for placebo does not occur for caffeine. Otherwise, caffeine and placebo did not appear to have any obvious distinctions.

Descriptive statistics for N1 amplitude across Drug, Cue and Time are shown in Table 6. The hypothesised Drug x Cue x Time interaction was non-significant, $F(2,32)=.090$, $p=.914$, $\eta_p^2=.006$. However, the Drug x Time interaction was significant, $F(1,16)=8.988$, $p=.009$, $\eta_p^2=.359$ (see Figure 9).

Table 6

N1 ERP Amplitude for Each Cue at Pre-ingestion and Post-Ingestion

	Placebo		Caffeine	
	Pre	Post	Pre	Post
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
No Cue	-0.99 (1.76)	-0.31 (2.27)	-0.96 (2.68)	-1.04 (2.19)
Central Cue	-1.44 (3.06)	-0.62 (2.03)	-1.17 (3.01)	-1.39 (2.84)
Spatial Cue	-4.36 (3.05)	-3.76 (2.56)	-3.76 (2.76)	-3.91 (2.73)

Note: M=Mean, *SD*=Standard Deviation.

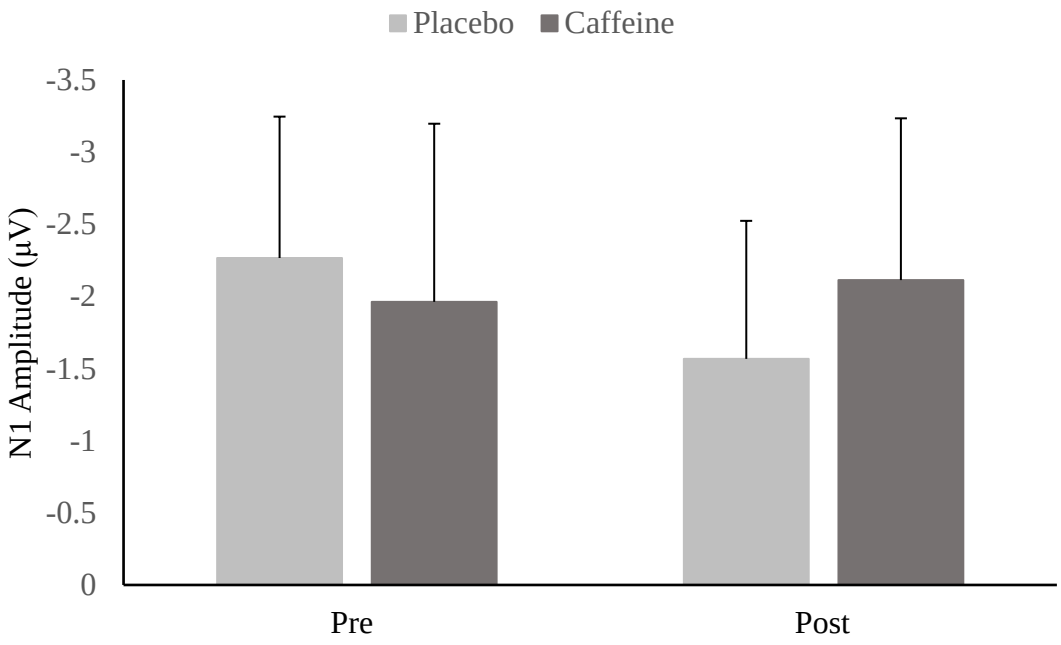

Figure 9. Grand averaged N1 ERP amplitude (μV) for Placebo and Caffeine at midline occipital electrode (Oz) at pre- and post-ingestion.

Analysis of main effects revealed significance for Cue, $F(2,32)=.42.68$, $p<.001$, $\eta_p^2=.73$, indicating a significantly greater overall amplitude for Spatial Cue (M=-3.95,

SD=1.37) relative to Central Cue (*M*=-1.16, *SD*=2.48) and No Cue (*M*=-.83, *SD*=2.05), *p*<.001, *g*=1.36, *p*<.001, *g*=1.65, respectively. Central and No Cue conditions were not significantly different, *p*=.351, *g*=0.14. Following placebo, amplitude (μV) at post-ingestion was significantly reduced from pre-ingestion, *p*=.002, *g*=0.46. While for caffeine, no significant difference was seen from pre-ingestion to post-ingestion, *p*=.536, *g*=0.09. At pre-ingestion and post-ingestion, no significant differences in amplitude occurred between placebo and caffeine, *p*=.429, *g*=0.18, *p*=.140, *g*=0.26, respectively.

Discussion

The present study examined the acute effects of caffeine (200mg) on behavioural (RT & accuracy) measures of alerting, orienting and executive control, and the electrophysiological (N1 ERP component) measures of alerting and orienting with healthy, low caffeine consumers. As hypothesised, RT decreased following caffeine compared with placebo, across cue and flanker conditions. Accuracy scores across cue and flanker conditions also improved following caffeine compared with placebo, as expected. Congruent and incongruent trials were also significantly faster following caffeine compared with placebo. While the prediction that caffeine would exert a greater effect upon the alerting and executive control networks was partially supported. A non-significant but meaningful group orienting effect was shown, somewhat contrary to expectation.

The prediction that the N1 amplitude would be smallest for no cue, greater for central cue, and greatest for spatial cue was partially supported. The hypothesis that for each cue the N1 amplitude would be significantly greater following caffeine compared with placebo was not supported. However, a significant Drug x Time interaction showed a significant reduction in N1 amplitude following placebo not seen for caffeine.

Taken together, these results suggest the improved RTs following caffeine for each cue and flanker type were not reflective of an effect of caffeine upon the alerting, orienting, or executive control networks. Rather, the improved scores on all aspects of the ANT following caffeine appear to primarily reflect a maintenance of tonic alertness and sustained attention.

Behavioural Measures of Attention

Evidence for the efficacy of the ANT was found, with a significant overall effect of Cue, whereby the spatial cue elicited faster RTs than the central cue, which elicited faster RTs than no cue (Fan et al., 2002). Within a significant Drug x Time x Flanker interaction, congruent flanker trials were also shown to be significantly faster than incongruent trials. A Drug x Time interaction trending toward significance showed an overall improvement in RT following caffeine compared with placebo. A non-significant and trivial difference between RT scores at pre-ingestion between placebo and caffeine conditions provided additional evidence for the efficacy of making comparisons between placebo and caffeine at post-ingestion. The hypothesised Drug x Time x Cue interaction trended toward significance and warranted further inspection. For each Cue condition RTs were faster following caffeine than placebo. Congruent and incongruent Flanker trials were shown to be significantly faster following caffeine compared with placebo, as indicated by a significant Drug x Time x Flanker interaction. A significant Drug x Time interaction for accuracy showed the percentage of correct responses both decreased following placebo and increased following caffeine. Taken together, these results strongly support the numerous previous studies showing an acute enhancement of attention following caffeine (Einöther & Giesbrecht, 2013; McLellen et al., 2016; Smith, 2002).

The specific contribution of each attentional mechanism following caffeine is less clear. The hypothesised Drug x Network interaction trended toward significance and warranted further analysis. However, after Bonferroni corrections were applied, no significant difference was seen between caffeine and placebo regarding alerting, orienting or executive control effects. This suggests the overall enhancement in RT following caffeine predominantly reflected a specific effect of caffeine upon tonic alertness. However, a significant Drug x Time x Flanker interaction also qualified a differential executive control effect, whereby trials containing incongruent flankers were responded to faster than congruent flankers from pre-ingestion to post-ingestion. The difference between placebo and caffeine was non-significant for the orienting network. However, a small-medium effect size (g=0.41) suggested that the orienting network was positively impacted by caffeine.

Giles et al. (2012) also found no significant effect of caffeine upon phasic alertness or orienting but did find a significant effect upon executive control. This same result was found in a follow up study (Giles et al., 2016). These results were suggested to mean caffeine did not influence early visual attention beyond improvements to general arousal and sustained attention (Giles et al., 2012). More specifically, it might be that a phasic alerting effect did not result because; a) the warning cue contains a ceiling effect, whereby general arousal (and subsequent performance) can only be elevated in response to the waring cue so far before performance is diminished, and b) the response readying effect of the warning cue is subsumed by the effect of caffeine upon tonic alerting. This explanation draws from previous work showing both the warning cue and caffeine can generate neural activation in the midbrain-thalamus-ACC network and pre-SMA, the same brain regions involved during tests of tonic alertness (Fan et al., 2005; Yanaka et al., 2010).

An alternate explanation for not finding a phasic alerting effect is that the 200mg dose of caffeine was too low. Some participants reported no caffeine consumption, while others reported both regular and fluctuating caffeine consumption (<150mg/day). James (2014) has argued that regular low use of caffeine, even as low as 70mg/day, can promote the up-regulation of adenosine receptors and subsequent tolerance and withdrawal effects. It was also argued that caffeine consumption is underreported due to its inconspicuous presence as an ingredient in numerous products. Subsequently, true phasic alerting effects of caffeine may have been masked by a low-level tolerance. This point is made particularly salient when considered in relation to the significant phasic alertness effect previously demonstrated by low caffeine consumers following a 200mg dose (Brunye et al., 2010a).

The effect of caffeine on the orienting network was not significantly different from placebo. However, a small-medium effect size (g=0.41) suggested that the orienting network was positively impacted by caffeine. Literature pertaining to orienting effects is scarce and limited and determining the effect of caffeine upon the orienting network is ongoing (McLellen et al., 2016). The current finding of a small-medium effect may have reflected a shared reliance on acetylcholine for tonic alertness and orienting, and the adenosine-antagonistic action of caffeine at prefrontal, frontoparietal, somatosensory, hippocampal, and visual cortices (Carter, 1995; Klinkenberg et al., 2010).

Studies that did not find a differential effect of caffeine upon the orienting network may have suffered from a lack of trials specifically assessing orienting. The present study utilised an ANT with 160 trials that specifically measured orienting, while previous studies used an ANT with 72 (Brunye et al., 2010a, 2010b; Giles et al., 2012; Giles et al., 2016). Results of previous studies could also reflect the shorter duration of

the ANT used; approximately 15 minutes compared to 28 minutes for the present study. The effects of caffeine upon the cholinergic system, and subsequent tonic alertness and orienting, might only be revealed over longer durations. However, the effect of orienting over-and-above tonic alertness was not significant following caffeine (despite the small-medium effect), and additional research is needed to determine the effect of caffeine upon the orienting network.

A significant Drug x Time x Flanker interaction suggested an executive control effect, whereby the difference in RT from pre-ingestion to post-ingestion for caffeine (but not placebo) was greater for congruent trials than incongruent trials. Put simply, caffeine appeared to improve the ability of an individual to inhibit distractive stimuli. This finding supports results of previous work (Brunye et al., 2010a, 2010b; Giles et al., 2012), but not all (Tieges et al., 2007). This pattern of results is thought to reflect caffeine as an adenosine antagonist and the consequent innervation of densely dopaminergic brain regions associated with executive functioning, such as the ACC and lateral prefrontal cortices (Fan et al., 2005).

Electrophysiological Measures of Attention

Neuhaus et al. (2010) showed a significant difference between no cue, central cue and spatial cue trials on the N1 ERP amplitude, whereby amplitude increased significantly with cue informativity. The present study did not find this pattern of results for placebo or caffeine conditions at either pre-ingestion or post-ingestion. The present study did show an increase in N1 amplitude from no cue and central cue to spatial cue for both caffeine and placebo conditions, but not from no cue to central cue. The pattern of results seen previously could be attributed to averaging across several electrode sites (Neuhaus et al., 2010), rather than specifically targeting an electrode at occipital midline (Oz). A significant Drug x Time interaction (p=.009, η_p^2=.359) showed an overall

significant reduction in amplitude did occur from pre-ingestion to post-ingestion following placebo. Considering this same drop in amplitude was not seen following caffeine, caffeine may have prevented this decline in amplitude, subsequently playing a role in the improved RT and accuracy scores.

The maintenance of cortical activity seen following caffeine provides evidence for an enhancement of sustained attention (Fu et al., 2005; Padilla et al., 2006). This finding aligns with work from Foxe et al. (2012) who monitored EEG activity during a SRT task following caffeine. Caffeine was found to significantly reduce the presence of alpha-band oscillations, an index of fatigue, compared to placebo. Caffeine seemingly prevented the normal decrease in cortical activity typically seen during lengthy, fatigue-inducing tasks (Pfurtscheller, 1992). Results of the present study also parallel with conceptions of caffeine as an adenosine modulator within the CNS, blocking adenosine, and sustaining overall neural activity (Urry & Landolt, 2014). The visually apparent reduction in amplitude on no cue trials from pre-ingestion to post-ingestion following placebo potentially supports this view, as no cue trials provide an index of tonic alertness. However, high variability in the N1 ERP dataset for Drug x Time x Cue suggests greater power is required to determine whether the significant Drug x Time interaction does extend to specific cues more so than others.

A significant Drug x Time x Flanker interaction for RT suggested the executive control network was differentially affected by caffeine than placebo. However, the present study was unable to determine whether the significant Drug x Time interaction for the ERP amplitude extended out to response inhibition. Executive functioning has been consistently indexed by N2 and P3 ERP components at frontal electrode sites (Neuhaus et al., 2010). However, few previous studies have examined the effect of caffeine upon ERP correlates of response inhibition (Barry et al., 2014; Kok et al.,

2004). While beyond the scope of the present study, future research that incorporates the N2 and P3 ERP components could provide valuable insights into the effects of caffeine upon neural correlates of response inhibition.

Mood, Fatigue, and Sleepiness

Drug x Time interactions for confusion-bewilderment (POMS-SF), vigour-activity (POMS-SF), fatigue-inertia (POMS-SF), and sleepiness (KSS) suggested several effects of caffeine upon mood and sleepiness. Following caffeine, participants of the present study reported significantly less symptoms of confusion compared with placebo. This can potentially be explained by the enhancement in response inhibition, and/or vice-versa (McLellen et al., 2016). Following caffeine, vigour-activity increased and sleepiness decreased, indicative of elevated enthusiasm and task readiness. These findings align with evidence showing an overall increase in general arousal and tonic alertness (Giles et al., 2016). Level of fatigue-inertia increased following placebo but was maintained with caffeine. This supports discussion points regarding the Drug x Time interaction for the N1 ERP amplitude, whereby the reduction in cortical activity at the occipital N1 following placebo, not seen following caffeine, was indicative of fatigue prevention (Pfurtscheller, 1992).

Practical Implications

Findings of the present study suggest caffeine enhances attentional capability in healthy, low consumers of caffeine, particularly for tasks requiring extended tonic alertness and response inhibition. This cognitive enhancement occurred without a speed-accuracy trade-off. Present results show a significant increase in accuracy following caffeine compared to placebo. Examples of tasks requiring efficient tonic alertness and response inhibition are numerous, and include driving, police stakeouts, scientific research, to name a few.

Present findings may also benefit research into age-related diseases such as Alzheimer's disease (Jeong, 2004; Panza et al., 2015). Alzheimer's disease (AD) is characterised by slowed mean EEG frequency, less complex cortical activity, and reduced coherences among cortical regions (Jeong, 2004). The present electrophysiological results suggest caffeine might prevent reductions in neural activity associated with sustained attention. Given present findings, EEG could provide a beneficial means of investigating the effects of caffeine upon symptoms of AD (Jeong, 2004; Panza et al., 2015).

Limitations

Post-ingestion manipulation checks indicated that participants were significantly more confident in having just experienced the effects of caffeine following the active condition than the placebo condition. This could have potentially resulted in drug expectancy effects, whereby following the placebo session, participants could return for their second session expecting to have caffeine, and subsequently act according to preconceptions about its attentional enhancing effects (Huntley & Juliano, 2012; Kirsch, 1997). Following the caffeine session, participants could have returned for their second session expecting to receive a placebo. Considering the duration of the ANT task, along with the confidence that the task would not be supplemented with caffeine, enthusiasm and subsequent effort for the ANT at post-ingestion could have been impacted (Kirsch, 1997). The non-significant differences in RT at pre-ingestion and large variability in caffeine confidence scores goes someway to refute the impact of drug expectancy effects on present results. However, future studies could include a baseline caffeine confidence check as an added precaution.

The present study also could have accounted for personality as a potentially confounding factor. Performance enhancing effects of caffeine have been shown to be

more pronounced for individuals high in extraversion, impulsivity, and novelty seeking than individuals high in introversion (Anderson, 1994; Gurpegui et al., 2007). These results have been attributed to lower levels of dopamine in high extraverts relative to high introverts (Gurpegui et al., 2007).

Conclusion

Considering the prevalence of caffeine consumption, it is essential to understand the effects of caffeine on attention and associated neural processes. Results of the present study add to the increasing body of literature showing that caffeine can be used as a cognitive enhancement on tasks of visual attention, particularly sustained attention and response inhibition. Not only furthering the literature pertaining to behavioural indices of attention, the present study appears to be the first to assess the effect of caffeine upon the visual N1 ERP component using an ANT.

More specifically, the attentional mechanisms effected by caffeine, at least for healthy, low consumers following a dose of 200mg caffeine, include the tonic alertness component of the alerting network and the response inhibition component of the executive control network. The significant improvements in RT and accuracy appear to primarily reflect an effect of caffeine on general arousal and tonic alertness, whereby attentional processing was maintained during the ANT following caffeine and not placebo. This view is supported by current electrophysiological findings which showed a decline in cortical activity at the occipital N1 component following placebo but not caffeine. Given the popularity of caffeine worldwide, these results carry meaningful implications regarding CNS functioning, and the way in which individuals choose to attend to and process information.

References

Adan, A., Prat, G., Fabbri, M. and Sànchez-Turet, M. (2008). Early effects of caffeinated and decaffeinated coffee on subjective state and gender differences. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 32(7), 1698-1703. Doi: https://doi.org/10.1016/j.pnpbp.2008.07.005

Addicott, M. A., & Laurienti, P. J. (2009). A comparison of the effects of caffeine following abstinence and normal caffeine use. *Psychopharmacology*, *207*(3), 423-431. Doi: https://doi.org/10.1007/s00213-009-1668-3

Åkerstedt, T. and Gillberg, M. (1990). Subjective and Objective Sleepiness in the Active Individual. *International Journal of Neuroscience*, 52(1-2), 29-37. Doi: https://doi.org/10.3109/00207459008994241

Anderson, K. J. (1994). Impulsitivity, caffeine, and task difficulty: A within-subjects test of the Yerkes-Dodson law. *Personality and Individual Differences*, *16*(6), 813-829. Doi: https://doi.org/10.1016/0191-8869(94)90226-7

Andrews, G., & Slade, T. (2001). Interpreting scores on the Kessler psychological distress scale (K10). *Australian and New Zealand journal of public health*, *25*(6), 494-497. Doi: https://doi.org/10.1111/j.1467-842X.2001.tb00310.x

Barry, R. J., De Blasio, F. M., & Cave, A. E. (2014). Caffeine effects on ERP components and performance in an equiprobable auditory go/nogo task. *Journal of caffeine research*, *4*(3), 83-92. Doi: https://doi.org/10.1089/jcr.2014.0011

Becker, M. W., & Leinenger, M. (2011). Attentional selection is biased toward mood-congruent stimuli. *Emotion*, *11*(5), 1248. Doi: http://dx.doi.org/10.1037/a0023524

Bohn, M. J., Babor, T. F., & Kranzler, H. R. (1995). The Alcohol Use Disorders Identification Test (AUDIT): validation of a screening instrument for use in medical settings. *Journal of Studies on Alcohol, 56*(4), 423-432. Doi: https://doi.org/10.15288/jsa.1995.56.423

Brunyé, T., Mahoney, C., Lieberman, H., Giles, G. and Taylor, H. (2010). Acute caffeine consumption enhances the executive control of visual attention in habitual consumers. *Brain and Cognition*, 74(3), 186-192. Doi: https://doi.org/10.1016/j.bandc.2010.07.006

Brunyé, T., Mahoney, C., Lieberman, H. and Taylor, H. (2010). Caffeine modulates attention network function. *Brain and Cognition*, 72(2), 181-188. Doi: https://doi.org/10.1016/j.bandc.2009.07.013

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, 51(13), 1484-1525. Doi: https://doi.org/10.1016/j.visres.2011.04.012

Carter, A. J., O'Connor, W. T., Carter, M. J., & Ungerstedt, U. (1995). Caffeine enhances acetylcholine release in the hippocampus in vivo by a selective interaction with adenosine A1 receptors. *Journal of Pharmacology and Experimental Therapeutics, 273*(2), 637-642.

Childs, E., & De Wit, H. (2006). Subjective, behavioral, and physiological effects of acute caffeine in light, nondependent caffeine users. *Psychopharmacology, 185*(4), 514. Doi: https://doi.org/10.1007/s00213-006-0341-3

Christopher, G., Sutherland, D., & Smith, A. (2005). Effects of caffeine in non-withdrawn volunteers. *Human Psychopharmacology: Clinical and Experimental, 20*(1), 47-53. Doi: https://doi.org/10.1002/hup.658

Cohen, J. (1973). Eta-squared and partial eta-squared in fixed factor ANOVA designs. *Educational and Psychological Measurement, 33*(1), 107-112. Doi: https://doi.org/10.1177/001316447303300111

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). New York: Routledge.

Cohen, J. (1992). A power primer. Psychological Bulletin, 112, 155 -159. Doi: 10.1037/0033-2909.112.1.155

Curran, S. L., Andrykowski, M. A., & Studts, J. L. (1995). Short form of the Profile of Mood States (POMS-SF): Psychometric information. *Psychological Assessment, 7*(1), 80. Doi: 10.1037/1040-3590.7.1.80

Durlak, J. A. (2009). How to select, calculate, and interpret effect sizes. *Journal of Paediatric Psychology*, *34*(9), 917-928. Doi: https://doi.org/10.1093/jpepsy/jsp004

Einöther, S. J., & Giesbrecht, T. (2013). Caffeine as an attention enhancer: reviewing existing assumptions. *Psychopharmacology, 225*(2), 251-274. Doi: https://doi.org/10.1007/s00213-012-2917-4

Epstein, R. (1984). The principle of parsimony and some applications in psychology. *The Journal of Mind and Behavior,* 119-130. Doi: https://www.jstor.org/stable/43853318

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics, 16*(1), 143-149. Doi: https://doi.org/10.3758/BF03203267

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, *14*(3), 340-347. Doi: https://doi.org/10.1162/089892902317361886

Fine, B. J., Kobrick, J. L., Lieberman, H. R., Marlowe, B., Riley, R. H., & Tharion, W. J. (1994). Effects of caffeine or diphenhydramine on visual vigilance. *Psychopharmacology*, *114*(2), 233-238. Doi: https://doi.org/10.1007/BF02244842

Foxe, J. J., Morie, K. P., Laud, P. J., Rowson, M. J., De Bruin, E. A., & Kelly, S. P. (2012). Assessing the effects of caffeine and theanine on the maintenance of vigilance during a sustained attention task. *Neuropharmacology*, *62*(7), 2320-2327. Doi: https://doi.org/10.1016/j.neuropharm.2012.01.020

Fu, S., Greenwood, P. M., & Parasuraman, R. (2005). Brain mechanisms of involuntary visuospatial attention: An event-related potential study. *Human Brain Mapping*, *25*(4), 378-390. Doi: https://doi.org/10.1002/hbm.20108

Giles, G. E., Mahoney, C. R., Brunyé, T. T., Gardony, A. L., Taylor, H. A., & Kanarek, R. B. (2012). Differential cognitive effects of energy drink ingredients: caffeine, taurine, and glucose. *Pharmacology Biochemistry and Behavior*, *102*(4), 569-577. Doi: https://doi.org/10.1016/j.pbb.2012.07.004

Gurpegui, M., Jurado, D., Luna, J. D., Fernández-Molina, C., Moreno-Abril, O., & Gálvez, R. (2007). Personality traits associated with caffeine intake and smoking. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *31*(5), 997-1005. Doi: https://doi.org/10.1016/j.pnpbp.2007.02.006

Haskell, C. F., Kennedy, D. O., Milne, A. L., Wesnes, K. A., & Scholey, A. B. (2008). The effects of L-theanine, caffeine and their combination on cognition and mood. *Biological psychology*, *77*(2), 113-122. Doi: https://doi.org/10.1016/j.biopsycho.2007.09.008

Hewlett, P., & Smith, A. (2006). Acute effects of caffeine in volunteers with different patterns of regular consumption. *Human Psychopharmacology: Clinical and Experimental*, *21*(3), 167-180. Doi: https://doi.org/10.1002/hup.752

Hunt, A. R., & Kingstone, A. (2003). Covert and overt voluntary attention: linked or independent?. *Cognitive Brain Research*, *18*, 102-105. Doi: https://doi.org/10.1016/j.cogbrainres.2003.08.006

Huntley, E. D., & Juliano, L. M. (2012). Caffeine Expectancy Questionnaire (CaffEQ): Construction, psychometric properties, and associations with caffeine use, caffeine dependence, and other related variables. *Psychological assessment*, *24*(3), 592. Doi: 10.1037/a0026417

James, J. E. (2014). Caffeine and cognitive performance: persistent methodological challenges in caffeine research. *Pharmacology Biochemistry and Behavior*, *124*, 117-122. Doi: 10.1016/j.pbb.2014.05.019

Jeong, J. (2004). EEG dynamics in patients with Alzheimer's disease. *Clinical Neurophysiology*, 115(7), 1490-1505. Doi: https://doi.org/10.1016/j.clinph.2004.01.001

Kelemen, W. L., & Creeley, C. E. (2001). Caffeine (4 mg/kg) influences sustained attention and delayed free recall but not memory predictions. *Human*

Psychopharmacology: Clinical and Experimental, *16*(4), 309-319. Doi: https://doi.org/10.1002/hup.287

Kenemans, J. L., Wieleman, J. S., Zeegers, M., & Verbaten, M. N. (1999). Caffeine and stroop interference. *Pharmacology Biochemistry and Behavior*, *63*(4), 589-598. Doi: https://doi.org/10.1016/S0091-3057(99)00022-2

Kessler, R. C., Andrews, G., Colpe, L. J., Hiripi, E., Mroczek, D. K., Normand, S. L., ... & Zaslavsky, A. M. (2002). Short screening scales to monitor population prevalences and trends in non-specific psychological distress. *Psychological Medicine, 32*(6), 959-976. Doi: https://doi.org/10.1017/S0033291702006074

Kirsch, I. (1997). Response expectancy theory and application: A decennial review. *Applied and preventive Psychology*, *6*(2), 69-79. Doi: https://doi.org/10.1016/S0962-1849(05)80012-5

Klinkenberg, I., Sambeth, A., & Blokland, A. (2011). Acetylcholine and attention. *Behavioural brain research*, *221*(2), 430-442. Doi: 10.1016/j.bbr.2010.11.033

Ko, J., Ptito, A., Monchi, O., Cho, S., Van Eimeren, T., Pellecchia, G., Ballanger, B., Rusjan, P., Houle, S. and Strafella, A. (2009). Increased dopamine release in the right anterior cingulate cortex during the performance of a sorting task: A [11C]FLB 457 PET study. *NeuroImage*, 46(2), 516-521. Doi: https://doi.org/10.1016/j.neuroimage.2009.02.031

Kok, A., Ramautar, J. R., De Ruiter, M. B., Band, G. P., & Ridderinkhof, K. R. (2004). ERP components associated with successful and unsuccessful

stopping in a stop-signal task. *Psychophysiology*, *41*(1), 9-20. Doi: https://doi.org/10.1046/j.1469-8986.2003.00127.x

Koppelstaetter, F., Poeppel, T. D., Siedentopf, C. M., Ischebeck, A., Kolbitsch, C., Mottaghy, F. M., ... & Krause, B. J. (2010). Caffeine and cognition in functional magnetic resonance imaging. *Journal of Alzheimer's Disease*, *20*(s1), S71-S84. Doi: 10.3233/JAD-2010-1417

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863. Doi: https://doi.org/10.3389/fpsyg.2013.00863

Liguori, A., Grass, J. A., & Hughes, J. R. (1999). Subjective effects of caffeine among introverts and extraverts in the morning and evening. *Experimental and clinical psychopharmacology*, *7*(3), 244. Doi: http://dx.doi.org/10.1037/1064-1297.7.3.244

Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, *4*(11), 432-440. Doi: https://doi.org/10.1016/S1364-6613(00)01545-X

Martin, F. H., & Garfield, J. (2006). Combined effects of alcohol and caffeine on the late components of the event-related potential and on reaction time. *Biological Psychology*, *71*(1), 63-73. Doi: https://doi.org/10.1016/j.biopsycho.2005.01.004

Myer, L., Stein, D. J., Grimsrud, A., Seedat, S., & Williams, D. R. (2008). Social determinants of psychological distress in a nationally-representative sample of South African adults. *Social science & medicine*, *66*(8), 1828-1840. Doi: https://doi.org/10.1016/j.socscimed.2008.01.025

Nehlig, A. (2010). Is caffeine a cognitive enhancer?. *Journal of Alzheimer's Disease*, *20*(s1), S85-S94. Doi: 10.3233/JAD-2010-091315

Neuhaus, A., Urbanek, C., Opgen-Rhein, C., Hahn, E., Ta, T., Koehler, S., Gross, M. and Dettling, M. (2010). Event-related potentials associated with Attention Network Test. *International Journal of Psychophysiology*, 76(2), 72-79. Doi: https://doi.org/10.1016/j.ijpsycho.2010.02.005

Nuwer, M. R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guérit, J. M., Hinrichs, H., ... & Rappelsburger, P. (1998). IFCN standards for digital recording of clinical EEG. *Clinical Neurophysiology*, *106*(3), 259-261. Doi: https://doi.org/10.1016/S0013-4694(97)00106-5

Oken, B. S., Salinsky, M. C., & Elsas, S. M. (2006). Vigilance, alertness, or sustained attention: physiological basis and measurement. *Clinical Neurophysiology*, *117*(9), 1885-1901. Doi: https://doi.org/10.1016/j.clinph.2006.01.017

Padilla, M., Wood, R., Hale, L. and Knight, R. (2006). Lapses in a Prefrontal-Extrastriate Preparatory Attention Network Predict Mistakes. *Journal of Cognitive Neuroscience*, 18(9), 1477-1487. Doi: https://doi.org/10.1162/jocn.2006.18.9.1477

Panza, F., Solfrizzi, V., Barulli, M. R., Bonfiglio, C., Guerra, V., Osella, A., ... & Logroscino, G. (2015). Coffee, tea, and caffeine consumption and prevention of late-life cognitive decline and dementia: a systematic review. *The journal of nutrition, health & aging*, *19*(3), 313-328. Doi: https://doi.org/10.1007/s12603-014-0563-8

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual review of neuroscience*, *35*, 73-89. Doi: https://doi.org/10.1146/annurev-neuro-062111-150525

Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest. *Electroencephalography and clinical neurophysiology*, *83*(1), 62-69. Doi: https://doi.org/10.1016/0013-4694(92)90133-3

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, *32*(1), 3-25. Doi: https://doi.org/10.1080/00335558008248231

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual review of neuroscience*, *13*(1), 25-42. Doi: https://doi.org/10.1146/annurev.ne.13.030190.000325

Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annu. Rev. Psychol.*, *58*, 1-23. Doi: https://doi.org/10.1146/annurev.psych.58.110405.085516

Ratcliff, R., & Van Dongen, H. P. (2011). Diffusion model for one-choice reaction-time tasks and the cognitive effects of sleep deprivation. *Proceedings of the National Academy of Sciences*, *108*(27), 11285-11290. Doi: https://doi.org/10.1073/pnas.1100483108

Renda, G., Committeri, G., Zimarino, M., Di Nicola, M., Tatasciore, A., Ruggieri, B., Ambrosini, E., Viola, V., Antonucci, I., Stuppia, L. and De Caterina, R. (2015). Genetic determinants of cognitive responses to caffeine drinking identified from a double-blind, randomized, controlled trial. *European*

Neuropsychopharmacology, 25(6), 798-807. Doi: https://doi.org/10.1016/j.euroneuro.2015.03.001

Revelle, W., Humphreys, M. S., Simon, L., & Gilliland, K. (1980). The interactive effect of personality, time of day, and caffeine: A test of the arousal model. *Journal of Experimental Psychology: General, 109*(1), 1. Doi: http://dx.doi.org/10.1037/0096-3445.109.1.1

Ruijter, J., Lorist, M., Snel, J. and De Ruiter, M. (2000). The Influence of Caffeine on Sustained Attention. *Pharmacology Biochemistry and Behavior*, 66(1), 29-37. Doi: https://doi.org/10.1016/S0091-3057(00)00229-X

Saunders, J. B., Aasland, O. G., Babor, T. F., De la Fuente, J. R., & Grant, M. (1993). Development of the alcohol use disorders identification test (AUDIT): WHO collaborative project on early detection of persons with harmful alcohol consumption-II. *Addiction, 88*(6), 791-804. Doi: https://doi.org/10.1111/j.1360-0443.1993.tb02093.x

Saville, C. W., de Morree, H. M., Dundon, N. M., Marcora, S. M., & Klein, C. (2018). Effects of caffeine on reaction time are mediated by attentional rather than motor processes. *Psychopharmacology, 235*(3), 749-759. Doi: https://doi.org/10.1007/s00213-017-4790-7

Shacham, S. (1983). A shortened version of the Profile of Mood States. *Journal of Personality Assessment, 47*(3), 305-306. Doi: https://doi.org/10.1207/s15327752jpa4703_14

Smith, A., Brice, C., Nash, J., Rich, N., & Nutt, D. J. (2003). Caffeine and central noradrenaline: effects on mood, cognitive performance, eye movements and

cardiovascular function. *Journal of Psychopharmacology*, *17*(3), 283-292. Doi:

Smith, A., Brice, C., Nash, J., Rich, N., & Nutt, D. J. (2003). Caffeine and central noradrenaline: effects on mood, cognitive performance, eye movements and cardiovascular function. *Journal of psychopharmacology*, *17*(3), 283-292. Doi: https://doi.org/10.1177/02698811030173010

Smith, A. P., Christopher, G., & Sutherland, D. (2013). Acute effects of caffeine on attention: a comparison of non-consumers and withdrawn consumers. *Journal of Psychopharmacology*, *27*(1), 77-83. Doi: https://doi.org/10.1177/0269881112460112

Smith, A., Maben, A., Brockman, P. (1993). The effects of caffeine and evening meals on sleep and performance, mood and cardiovascular functioning the following day. *Journal of Psychopharmacology, 7(2),* 203–206. Doi: https://doi.org/10.1177/026988119300700209

Smith, A., Sutherland, D., & Christopher, G. (2005). Effects of repeated doses of caffeine on mood and performance of alert and fatigued volunteers. *Journal of Psychopharmacology*, *19*(6), 620-626. Doi: https://doi.org/10.1177/0269881105056534

Snel, J., & Lorist, M. M. (2011). Effects of caffeine on sleep and cognition. In *Progress in Brain Research* (Vol. 190, pp. 105-117). Elsevier. Doi: https://doi.org/10.1016/B978-0-444-53817-8.00006-2

Tieges, Z., Ridderinkhof, K. R., Snel, J., & Kok, A. (2004). Caffeine strengthens action monitoring: evidence from the error-related negativity. *Cognitive Brain Research*, *21*(1), 87-93. Doi: https://doi.org/10.1016/j.cogbrainres.2004.06.001

Tieges, Z., Snel, J., Kok, A., & Ridderinkhof, K. R. (2009). Caffeine does not modulate inhibitory control. *Brain and Cognition*, *69*(2), 316-327. Doi: https://doi.org/10.1016/j.bandc.2008.08.001

Urry, E., & Landolt, H. P. (2014). Adenosine, caffeine, and performance: from cognitive neuroscience of sleep to sleep pharmacogenetics. In *Sleep, Neuronal Plasticity and Brain Function* (pp. 331-366). Springer, Berlin, Heidelberg. Doi: https://doi.org/10.1007/7854_2014_274

Volkow, N. and Morales, M. (2015). The Brain on Drugs: From Reward to Addiction. *Cell*, 162(4), 712-725. Doi: https://doi.org/10.1016/j.cell.2015.07.046

Wechsler, D. (2001). *Weschler Test of Adult Reading (WTAR)*. San Antonio: The Psychological Corporation.

Yanaka, H., Saito, D., Uchiyama, Y. and Sadato, N. (2010). Neural substrates of phasic alertness: A functional magnetic resonance imaging study. *Neuroscience Research*, 68(1), 51-58. Doi: https://doi.org/10.1016/j.neures.2010.05.005

Yang, A., Palmer, A. A., & de Wit, H. (2010). Genetics of caffeine consumption and responses to caffeine. *Psychopharmacology*, *211*(3), 245-257. Doi: https://doi.org/10.1007/s00213-010-1900-1

Appendix A

Dear Dr Matthews,

Ethics Ref: H0016995
Title: The effects of Caffeine on Attentional Networks

This email is to confirm that the following amendment was approved by the Executive Officer on behalf of the Tasmania Health and Medical Human Research Ethics Committee on 7/6/2018:

Amendment each session from 2 to 3 hours and value of gift voucher details
Protocol Ethics protocol_amendment_260518

All committees operating under the Human Research Ethics Committee (Tasmania) Network are registered and required to comply with the National Statement on Ethical Conduct in Human Research (NHMRC 2007).

This email constitutes official approval. If your circumstances require a formal letter of amendment approval, please let us know.

Should you have any queries please do not hesitate to contact me.

Kind regards

Jude Vienna-Hallam
--
Jude Vienna-Hallam
Ethics Officer
Office of Research Services
University of Tasmania
Private Bag 01
Hobart TAS 7001
Phone: (03) 6226 6254
Fax: (03) 6226 2765

Appendix B

Experimental session questionnaire

Date ____/____/____ Participant ID

_____

1. **Check that participant has abstained from alcohol for 24 hours and illicit drug use since completing the screening questionnaire**
2. **Weight _____ kg**

   Height_____ cm

   BMI _____
3. **Have you consumed any medications in the past week (or any prescribed medications since completing the screening questionnaire)?**

   If yes, please detail:

Medication	Number of occasions	Time since last used	Estimated dose

4. **How many cups of coffee (or any other caffeinated drinks/products) have you consumed today? _____**

   If > 0. How many hours since your last caffeinated drink _____ hours
5. **Have you had any tobacco or nicotine products today? Yes / No**

   If yes, how many cigarettes (or nicotine products) have you had today? ____

   If yes, How many hours since your last cigarette (nicotine product) _____ hours
6. **What have you had to eat today? How long since you last ate something? _____mins**

_____

_____

_____

_____

7. **Approximately how many hours sleep did you have last night? ____**

Appendix C

Participant Code:

Test Point: pre/post

Visual Analogue Scales of Subjective Performance

Please mark on each line at the point which most accurately reflects your level of agreement AT THE MOMENT with the below statement:

1. I feel alert

STRONGLY AGREE ——————————————— STRONGLY DISAGREE

2. I feel that I will be able to perform the attention tasks to the best of my ability

STRONGLY AGREE ——————————————— STRONGLY DISAGREE

3.I do not feel that my driving would be impaired right now

STRONGLY AGREE ——————————————— STRONGLY DISAGREE

4.I feel capable of driving safely right now

STRONGLY AGREE ——————————————— STRONGLY DISAGREE

Visual Analogue Scales of Subjective Drug Effects

Participant number:

Test point: post

Please mark on each line at the point which most accurately reflects your level of agreement AT THE MOMENT with the below statement:

1. Strength of drug effect

NO EFFECT ——————————————————————— VERY STRONG EFFECT

2. Liking of the drug effect

DISLIKE VERY MUCH ——————————————————————— LIKE VERY MUCH

3. Alert level

NOT ALERT ——————————————————————— VERY ALERT

4. Intoxication

NOT INTOXICATED ——————————————————————— VERY INTOXICATED

How sure are you out of 100% that you have taken caffeine today?_____

Appendix D

ID Number_____

INFORMATION SHEET

The Effect of Caffeine on Attentional Networks

Chief Investigators: Dr Allison Matthews & Assoc. Prof. Raimondo Bruno

Researchers: [Add student researchers]*

****This research is being conducted as part of an Honours degree in the School of Psychology, UTAS.*

We invite you to participate in a study aiming to understand how caffeine affects cognitive processes such as attention and associated brain activity. It is important to understand how caffeine affects attention and this may have implications for driver and worker safety.

Why have I been invited to participate in this research?

You are invited to take part in the study if you are aged 18-30 years old and if you typically consume a no more than 100mg of caffeine per day (approximately 1 single shot of coffee, or 1 x energy drink, or 2 x cups of tea), and experience no adverse effects when you do consume caffeine. In order for the results of the study to be clear, all participants need to have normal or corrected to normal vison and hearing, speak English fluently, have no previous neurological, serious physical, or mental health problems, or current use of psychoactive medications. In addition, participants must NOT regularly use illicit drugs, smoke cigarettes daily, or consume alcohol at harmful levels. Female participants must not currently be pregnant or breast-feeding

What will my participation involve?

Participation is unlikely to cause any discomfort or distress. Firstly, if you are interested in taking part in the study, you will be invited to complete a confidential screening questionnaires including some basic information about yourself (such as age, sex, years of schooling) and to ensure that you are not taking medications or experiencing other issues that may affect brain activity. This will include a psychological distress scale, and some questions regarding your alcohol and drug use. All data collected will be kept in the strictest confidence as described below.

Participation will involve two 2-hour sessions at the Cognitive Neuroscience Lab at the University of Tasmania in Hobart. During each testing session, you will be fitted with an electrode cap for measuring your brain activity. You will then be asked to complete some

computer-based tasks which relate to cognitive processes such as attention. In these tasks you will respond with a button press when particular objects appear on the screen. Before completing the tasks for a second time, you will be asked to ingest a capsule which may contain either caffeine or placebo. The caffeine doses used in this study have been considered safe by a panel of experts and are unlikely to cause any adverse effects. First year psychology students will receive up to 4 hours course credit. Other participants will receive a $30 gift voucher for reimbursement of time and out-of-pocket expenses.

In the unlikely event that you do experience unpleasant side effects while completing the testing, a first aid officer will be available on site to provide further assistance if required. Additionally, the researcher will explain that in the unlikely event of you experiencing an adverse reaction once you have left the premises, you should contact your doctor or be taken to hospital immediately.

There are no specific risks associated with the measurement of brain activity. However, if you have sensitive skin there is a small possibility of a slight skin reaction from electrode preparation materials. If you believe there is a chance that your skin may react, you are advised to reconsider participation.

How private is the information that I give?

All data collected will be kept in the strictest confidence. All data will be identified by a coding system and no names or contact numbers will appear on any records. In this way, your identity is protected, and there will be no risk of legal or social problems arising from your participation in the study. Your contact information will be kept in a separate password protected file with your ID code, and this file will only be accessible to the researchers.

All information gathered in the study will be reported as grouped data, and because no personal information is recorded, no individual participants will be identifiable. Data from the study will be stored securely for fifteen years in locked cabinets or secure computer servers at the University of Tasmania, as is legally required, and then securely destroyed.

Can I withdraw from the research if I wish?

Participation in this study is entirely voluntary. You may, at any time, decline to answer any question you so wish, or withdraw from the study without effect or explanation.

You will be given a copy of this information sheet to keep. Please keep this in case you decide at a later date that you would like to retract your data from the study. If you wish to withdraw your data, you may request this prior to the 31st of August, 2018, after which time the results will be published and your contact information will be destroyed.

Who do I need to contact if I have any questions about the research?

If you would like more information about the research, please contact Dr Allison Matthews on 62267236 (or email Allison.Matthews@utas.edu.au). If you would like to find out about the results of the study, these will be available from Dr Matthews after January 2019 or at the Utas Cog Neuro Lab facebook page

Has this research been approved by an ethics committee?

This project has been approved by the Tasmanian Health and Medical Human Research Ethics Committee. If you have any concerns of an ethical nature, or complaints about the manner in which the study is conducted, you may contact the Executive Officer of the Human Research Ethics Committee (Tasmania) Network on (03) 6226 7479 or human.ethics@utas.edu.au. Please quote the ethics reference number H11386.

Who can I contact if I have any concerns?

If you have any personal concerns related to the study, you may choose to discuss these concerns confidentially with a counsellor at the University Psychology Clinic free of charge. Confidential appointments may be made on (03) 6226 6254.

Thank you for your interest in the study and for taking the time to read this information sheet. We hope you will be interested in participating in this study.

Allison Matthews & Raimondo Bruno

Chief Investigators

(03) 6226 7236 or (03) 6226 2190

XXX / XXX

Student Researchers

CONSENT FORM

The Effect of Caffeine on Attentional Networks

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1. I have read and understood the 'Information Sheet' for this study.
2. I understand that the dose of caffeine used in the study is not expected to give rise to any serious safety concerns
2. The nature and possible effects of the study have been explained to me.
3. I understand that the study involves:
    - Attending two testing sessions of approximately two hours duration
    - Consuming a capsule which may contain caffeine
    - Completing a series of questionnaire and computer tasks while my brain activity is measured
5. I understand that all research data will be securely stored on the University of Tasmania premises for five years, and will then be destroyed.
6. Any questions that I have asked have been answered to my satisfaction.
7. I agree that research data gathered from me for the study may be published provided that I cannot be identified as a participant.
8. I understand that the researchers will maintain my identity confidential and that any information I supply to the researcher(s) will be used only for the purposes of the research.
9. I agree to participate in this investigation and understand that I may withdraw any time without any effect. I may also request to withdraw my data from the research prior to the 31st August, 2018.

Name of Participant:

Signature: Date:

Statement by Investigator

☐ I have explained the project & the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation

Name of Investigator:

Signature: Date: